# Publications of the Yerkes Observatory

## Observatory

### VOLUME III PART II

## THE SPECTRUM OF THE HIGH POTENTIAL DISCHARGE BETWEEN METALLIC ELECTRODES IN LIQUIDS AND IN GASES AT HIGH PRESSURES

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By George E. Hale and Norton A. Kent

## INTRODUCTION

In February, 1901, shortly after the appearance of *Nova Persei*, experiments were undertaken in the spectroscopic laboratory of the Yerkes Observatory, in the hope that some light might be thrown upon the phenomena of temporary stars. It seemed desirable to repeat the important experiments of Wilsing, whose work on the spectrum of the high potential discharge between metallic poles in liquids had led him to propose a new theory to account for these abnormal celestial outbursts. Prior to the work of Wilsing the presence in the spectra of temporary stars of compound lines, having a bright component toward the red and a dark one toward the violet, had usually been accounted for as a result of Doppler's principle. It was supposed that the sudden outburst of light had arisen from the collision of two bodies moving with enormous velocities in the line of sight. The approaching body was supposed to give a spectrum of dark lines and the receding body a spectrum of bright lines. Thus in the integrated light of the two there should appear compound lines similar to those observed in *Nova Aurigae*. It was recognized, however, that this hypothesis was not without difficulties, which were greatly increased later when the spectrum of *Nova Normae* was found to resemble closely that of *Nova Aurigae*, and when it was recognized that the spectrum of *P Cygni* (the *Nova* of 1600) was characterized by similar pairs of lines. In all cases the dark lines were the more refrangible and the bright lines the less refrangible members of the pairs, while the velocities corresponding to their relative displacements were far in excess of the velocities of any celestial objects ever observed with the spectroscope. It was also a noteworthy fact that the distance between the lines, and consequently the corresponding relative velocities of the stars, underwent no important change during the period of visibility.

Subsequent to the publication of Wilsing's first paper, and prior to the outburst of *Nova Persei*, it had been generally recognized that the compound spectrum of *Nova Aurigae* might fairly be regarded as typical of temporary stars. This view had been confirmed by the observations of *Nova Carinae* in 1895, and of *Nova Sagittarii* and *Nova Aquilae* in 1898 and 1899, respectively; for these stars showed a similar spectrum. Nevertheless, many spectroscopists still adhered to an explanation based upon Doppler's principle. This was doubtless due to the fact that Wilsing's hypothesis offered an insufficient explanation of some of the most characteristic phenomena of temporary stars. Though presumably due to pressure, the shifts of the lines which he had measured in the spectrum of the spark in liquids did not seem altogether harmonious with the pressure shifts obtained by Humphreys and Mohler in gases, nor did Wilsing's assumption that pressures of several hundred atmospheres were involved seem consonant with the known physical conditions of the experiment. Finally, to omit mention of various minor objections, the dark lines in the spectra of temporary stars were known to be greatly displaced toward the violet, while the bright lines occupied nearly normal positions; whereas in the spark spectra recorded by Wilsing the dark lines were but little displaced, while the bright lines were considerably shifted toward the red.

It was with such questions as these in mind that the first experiments at the Yerkes Observatory were undertaken. Few results of importance, however, could be obtained with the induction

coils then available; and, in the absence of a suitable alternating dynamo, the discharge obtained in water was so unsatisfactory that the experiments had to be postponed. It fortunately became possible to renew them in the following summer, through the acquisition of a 1 K. W. Lakon transformer, giving 15,000 or 30,000 volts on open circuit, and the opportunity of using, through the kindness of Professor Crew, a 3. 3 K. W. alternating dynamo giving 110 volts.[1] With this apparatus, together with a large condenser and various accessories supplied through the kindness of Dr. George S. Isham and Mr. James Lyman, we were able to repeat Wilsing's experiments, and to extend them in various directions.

The possibility of varying the nature of the spectrum by altering the character of the high potential discharge was encountered early in our work, and has led us to undertake various investigations, some of which, if sufficiently developed, might ultimately possess considerable interest, especially from a physical or a chemical standpoint. In the course of these investigations it has been necessary to bear in mind the principal object of this research, viz., the bearing of the results on Wilsing's pressure theory of temporary stars. Nevertheless, we have thought it desirable to touch upon certain physical and chemical aspects of the problem, which, however, we have developed only far enough to suggest investigations which may prove to be worth undertaking in physical or chemical laboratories. The work on spark spectra in liquids comprises Part I of the present paper.

In attempting to form a clear conception of the phenomena of the high potential discharge in liquids, it was felt that an investigation should also be made of the spectrum of the high potential discharge in air and other gases at high pressures. The previous work of Humphreys and Mohler on the low potential discharge in air at pressures up to $14\frac{1}{2}$ atmospheres had proved of great interest and importance from an astrophysical standpoint. This had led to the general adoption of a law of pressure-shifts, in which the change of wave-length is expressed as directly proportional to the total pressure of the surrounding air. It seemed probable that investigations made primarily for the purpose of elucidating the phenomena previously encountered in liquids might also render possible an extension of this law, or at least give a basis for the discussion of any differences in character which the low potential and the high potential discharges might exhibit. We hardly expected to find, however, that phenomena resembling those observed in liquids could be reproduced in gases at moderate pressures. Unfortunately, the removal of Dr. Kent from the Yerkes Observatory put a stop to this part of the investigation before it was fairly begun. An account of the few results obtained is nevertheless given in Part II of the present paper, as they are of some interest for comparison with the phenomena observed in liquids. No general discussion of these results is attempted, for lack of sufficient data.

Part III comprises a brief outline of the spectroscopic phenomena of temporary stars and some remarks on the bearing of our results on Wilsing's pressure theory. It is evident that the experiments we have been able to undertake are wholly insufficient, both in variety and extent, to provide a suitable foundation for a general discussion. We have therefore been compelled to limit ourselves to such considerations as are suggested by the work in hand, leaving a continuation of the discussion for some future occasion, when further data may be available.

The paper concludes with a summary of the results of our investigation.

[1] This alternator was subsequently purchased by Dr. George S. Isham for permanent use in the spectroscopic laboratory of the Yerkes Observatory.

## I.  THE SPECTRUM OF THE HIGH POTENTIAL DISCHARGE BETWEEN METALLIC ELECTRODES IN LIQUIDS

### PREVIOUS INVESTIGATIONS

The possibility of producing compound spectra, consisting of pairs of bright and dark lines, by means of a high potential discharge in liquids, was first shown by Wilsing in 1899.  He was led to undertake these experiments by the desire to extend the investigations of Humphreys and Mohler, whose work on the low potential discharge in compressed air covered the range from 1 to $14\frac{1}{2}$ atmospheres.  The work of Humphreys and Mohler had shown that the effect of pressure in an atmosphere of air surrounding an electric arc was to produce a displacement toward the red of the metallic lines given by the arc.  Many of these lines were reversed, but special attention was called to the fact that the dark central lines of the reversals were displaced equally with the bright lines.  It was also pointed out that the lines were but little widened by the effect of pressure.

As the lines were shifted at a pressure of 12 atmospheres by only about 0.05 tenth-meter, it appeared that in order to account for the relative displacements of the bright and dark lines in the spectrum of *Nova Aurigae*, amounting to from 10 to 20 tenth-meters, pressures of several hundred atmospheres might be needed.  In order to avoid the experimental difficulties which the production of such high pressures might involve, Wilsing decided to investigate the spectra of high potential discharges in liquids, taking advantage of the pressure effect produced by the spark itself.  Previous investigations along this line, beginning with the work of Masson, had not been quantitative in character, and seemed to have little or no bearing upon the questions at issue.[2]

The apparatus used by Wilsing in his experiments is described by him as follows:

I employed in my experiments a large inductorium, in the secondary circuit of which a spark-gap was inserted before the electrodes in the usual way, in addition to the battery.  With the passage of each spark a blinding discharge took place between the electrodes in the water, giving a very intense continuous spectrum crossed by faint lines.  As the brightness of the continuous background and the flickering due to the irregularity of the discharge hindered the direct visual measurement of the lines, I photographed the discharge spectra in water and air on the same plate with a spectrograph, thus rendering possible a convenient and accurate determination of the relative position of the systems of lines of the two spectra.  The length of the prismatic spectrum between λ 4800 and λ 4600 was about 50 mm., and the wave-lengths of sharp lines could be determined within a few hundredths of a tenth-meter.  Besides this, Professor Lohse and Dr. Hartmann were kind enough to make me several plates with a grating spectrograph of high dispersion, and with a large prism spectrograph.[3]

In view of the results obtained in the present investigation, it is unfortunate that the spark apparatus employed by Wilsing was not more minutely described, as we now know that the exact conditions under which the discharge is produced have a most important bearing upon the spectroscopic phenomena obtained.

With this apparatus Wilsing investigated the spectrum of the spark in water between terminals of iron, nickel, platinum, copper, tin, zinc, cadmium, lead, and silver.  In the spectrum of iron he found numerous pairs of lines in which the bright component was displaced considerably toward the red, while the dark lines were displaced by smaller amounts, in some cases toward the red and in others toward the violet.  Certain isolated bright lines, unattended by dark companions, were similarly displaced toward the red.  Reference is made to the fact that these lines are faint and ill-defined on the less refrangible edge.  The displacements of a number of iron lines were measured by Wilsing; some of the results are given in Table I, where *e* denotes an emission line and *a* an absorption line.  In the second column of Table I are appended, for comparison, values of the shifts of the same lines as given by our plate No. 666, which appears to have about the same degree of absorption as Wilsing's photograph.

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[2]For an outline of the earlier work see Wilsing, *Astrophysical Journal*, Vol. X (1899), p. 116.    [3]*Ibid.*, p. 118.

Wilsing points out that the apparent shift is greatest for bright lines which are accompanied by more refrangible absorption lines. This is due to the presence of two strata of vapor near the electrodes, "the inner and hotter of which gives broadened and displaced lines, while the outer and cooler gives a normal spectrum with narrow lines." Hence the violet side of the bright lines will be obscured by the absorption of the cooler vapor, leaving on the red side of the absorption line only the portion produced by broadening. For this reason Wilsing remarks that measurements of such bright lines cannot be depended upon to give a normal displacement. In other cases, depending upon certain variations in the intensity of the discharge and the development of vapors at the electrodes (which are not explained in the paper), the emission and absorption spectra change places, and may perhaps overlap each other in the integrated image.

TABLE I

SHIFTS AS MEASURED BY WILSING AND BY KENT

(Degrees of absorption on the two plates approximately identical)

| Wave-Lengths of Lines* | Displacements toward the Red in Tenth-Meters: Positive Unless Otherwise Stated | | Type of Line e signifies emission a signifies absorption |
| --- | --- | --- | --- |
| | Wilsing | Plate 666   Kent | |
| 3749.64 | 0.09 | 0.03 | a |
| | .81 | .54 | e |
| 65.70 | .13 | .10 | e |
| 67.32 | .05 | .01 | a |
| | .17 | .31 | e |
| 3815.99 | −.07, −0 22 | .01 | a |
| | .51,   1.12 | .45 | e |
| 27.98 | −.10, −0.16, 0.00 | .00 | a |
| | .92,   1.06, 0.76 | .37 | e |
| 34.38 | −.07 | .01 | a |
| | .36 | .38 | e |
| 4071.92 | .11 | .03 | a |
| 4118.72 | .22 | .03 | e |
| 4199.27 | .16 | .06 | e |
| 4307.96 | −.05 | −.01 | a |
| | 1.12 | .44 | e |
| 83.71 | .00 | −.01 | a |
| | 1.33 | .48 | e |

* Wave-lengths of lines and intensities taken from Exner and Haschek's tables of the spark spectrum of iron.

Various metals other than iron were also used by Wilsing. With platinum the lines were slightly diffuse, but no appreciable displacement could be detected. With nickel the lines were broader and more displaced than in the case of iron. Copper gave broad bands, which were even more characteristic of tin, zinc, and cadmium, where the displacements were very great. Some of these bands contain narrow maxima of intensity. While well-defined toward the violet, the bands were rather diffuse toward the red, though they usually had a more or less distinct boundary on this side, beyond which the intensity of the bright band fell off rapidly. In the zinc spectrum a prominent absorption line was found, considerably displaced toward the red. The strong cadmium line λ 4413.23 was not displaced, but merely symmetrically broadened. Silver gave no lines; a continuous spectrum only was present. Additional peculiarities were noticed in the case of magnesium, lead, and other metals.

In his further account of the results, Wilsing remarks:

The magnitude of the displacement and the broadening of the metallic lines is, indeed, of a similar order in the case of the various plates, but noticeable differences nevertheless occur, which are in part to be attributed to the different duration of exposure and development of plates, but chiefly to the varying intensity of discharge, which changes with the strength of the current and the distance of the electrodes.

Wilsing suggested that it would be desirable to investigate the spectra in different liquids, and indeed tried both water and alcohol; but no appreciable differences were found in these two cases, and with oils the liquid was so rapidly clouded by decomposition that no photographs of the spectra could be obtained.

Wilsing remarks that his results are in agreement with those of Humphreys and Mohler, because in both investigations the lines in the spectra of tin, zinc, and cadmium suffered greater displacements than those in the spectra of iron and platinum. Assuming a proportionality between pressure and displacement, he concluded that the pressure resulting from the discharge in water must amount to several hundred atmospheres.

In commenting on these results, Kayser[4] states that he considers a quantitative comparison with the results of Humphreys and Mohler impossible. In this connection he points out that these investigators found the following displacements at a pressure of 12 atmospheres: Pt 0.02 tenth-meters, Fe 0.025, Cu 0.033, Sn 0.055, Zn 0.057; whereas Wilsing found: Pt 0.00, Fe up to 1.00, Cu up to 5.00, Sn up to 2.50, Zn up to 6.00.

In a paper read before the Royal Society on March 6, 1902[5] Lockyer describes his experiments at the South Kensington Observatory on spark spectra between metallic poles in water, and discusses their bearing on the results of Wilsing and the theory of temporary stars. In his earlier experiments the large Spottiswoode coil, capable of giving a 105 cm. spark in air, was used with a large glass plate condenser so that a spark 3 mm. long in air and about 0.5 mm. long in water was produced. Subsequently a 25 cm. coil was used in place of the larger one. With the latter coil, employed with a 45-liter Leyden jar, placed in parallel with the secondary circuit, photographs were made of the spark spectra of several metals in water, using a 15 cm. Rowland grating of 6.5 meters radius of curvature. Of the six metals examined only three—iron, zinc, and magnesium—showed reversals of the principal lines. In discussing his results Lockyer refers to the existence of several types of lines in the spectrum of a given element, and points out that in many cases the unsymmetrical reversals obtained closely resemble reversals which he had observed in the electric arc in air many years before. He divides the lines investigated into three types, as follows: (1) broadened bright lines, sharply defined toward the violet and diffuse toward the red; (2) broadened bright lines with central absorption; (3) broadened bright lines with non-symmetrical absorption, maximum of emission toward red.

Lockyer refers to variations in the relative intensities of certain lines, but he apparently did not recognize that the relative intensities, as well as the displacements of the lines and the absorption phenomena, can be varied between wide limits by such methods as will be described in the present paper.

In discussing the bearing of his results on Wilsing's theory of temporary stars, he concludes that "the pairs of bright and dark lines shown in the spectra of new stars do not arise from the cause which produces the appearances presented in the spectrum of the spark in water."

Konen's work[6] was devoted more particularly to the low potential discharge in liquids, but also contains important results obtained with the high potential discharge in water and other liquids. He distinguished between the results obtained with (1) the glow discharge; (2) the brush discharge; (3) the uncondensed spark; and (4) the condensed spark. He employed two induction coils, one giving a spark 30 cm. long, the other a very large coil made by Klingelfuss, giving a spark 1 m. long. This coil was supplied with currents up to 25 amperes developed by a storage battery. The primary current was made and broken by a Foucault interrupter, while the secondary spark could be condensed by the introduction of capacity to a length of 7 or 8 mm. in air, or 1 mm. in water. In

[4] *Handbuch der Spectroscopie*, Vol. I, p. 228.

[5] *Proceedings of the Royal Society*, Vol. LXX (1902), p. 31.

[6] H. Konen, "Ein Beitrag zur Kenntniss spectroskopischer Methoden," *Annalen der Physik*, Vol. IV, No. 9 (1902), p. 742.

series with this spark was an adjustable air-gap. Electrodes of various diameters and shapes were employed, and the spectrum of the spark in a large number of liquids was photographed. No experiments were made on the effect of self-induction.

Konen's observations on the glow and brush discharges need not be referred to here, as they did not give the spectra of the electrodes, and such discharges were not employed in the course of our own investigation. With the condensed discharge short explosive sparks were obtained, which undoubtedly produced considerable pressure in the liquid. Konen found in all cases, as Wilsing had done, that the spectrum of the condensed spark contained both bright and dark lines. From this and other remarks in his paper it appears that he did not produce any important changes in the character of the spectra by changing the constants of the circuit. He was also unable to repeat our experiments, briefly described in a paper published in March, 1902,[7] which showed that the use of strong salt solutions will tend to increase the number and strength of reversals. Konen criticises Lockyer's contention that the phenomena observed are due simply to unsymmetrical reversal, and points out that Lockyer overlooked various types of lines. He also remarks that the displacements are very different for different lines, and considers that it would be useless to attempt an explanation of the phenomena given by the spark in liquids in the absence of more detailed investigations. From the table of wave-lengths and intensities which accompanies Konen's article, it would appear that his conditions corresponded closely with those which obtained in our own work when considerable self-induction was used in the discharge circuit. In the extreme ultra-violet, where the nature of our apparatus did not permit us to work, Konen found displacements of bright iron lines toward the red as great as 2 tenth-meters. In this region ($\lambda$ 2606—$\lambda$ 2755) the lines in his photographs were sharp. Konen also gives some results for aluminium and copper.

Three preliminary notes on our own experiments have been published. In the first of these[8] a brief account is given of our earlier results, showing that the reversal phenomena could be controlled by varying the electrical constants of the discharge circuit, and the nature of the liquid. In this paper it was stated that no dark lines were obtained in the spectrum of the discharge of an Apps induction coil. It was subsequently found that this result was due to the particular conditions under which the experiment was made, and that this coil will give results similar to those obtained by our transformers. It was also stated that the preliminary experiments to test the effect of self-induction had given negative results, but that they were regarded as inconclusive and would be repeated. With more suitable apparatus we have since found that the most satisfactory way of controlling the absorption phenomena is by varying the self-induction in the discharge circuit.

A second note[9] refers to the fact that in the spark spectra of a large number of metals the reversals first appear in the ultra-violet, and advance gradually toward the less refrangible region as the conditions for reversal become more favorable, thus corresponding with the results previously obtained by Liveing and Dewar with the electric arc. In a third note[10] we have given further results obtained with the spark in liquids, and a preliminary account of our more recent work on the spark in gases at high pressures.

### APPARATUS

The apparatus employed during this investigation was as follows:

A. For producing the spark:

1. A 3.7 K. W. shunt-wound Weston motor, fed from the main 110-volt circuit of the Observatory power-house.

[7] *Astrophysical Journal*, Vol. XV (1902), p. 132.

[8] GEORGE E. HALE, "Note on the Spark Spectrum of Iron in Liquids and in Air at High Pressures," *ibid.*

[9] GEORGE E. HALE, "Selective Absorption as a Function of Wave Length," *ibid.*, p. 227.

[10] GEORGE E. HALE and N. A. KENT. "Second Note on the Spark Spectrum of Iron in Liquids and Compressed Gases," *ibid.*, Vol. XVII (1903), p. 154.

2. A 3.3 K. W. 8-pole alternator (amperes 30, volts 110), which gave, at 1,875 revolutions per minute (its normal speed), 125 complete cycles per second. As exciting current, the regular 110-volt circuit was used. In this circuit was placed a 50-step General Electric resistance box, which gave a maximum resistance of 75 ohms, or 1.5 ohms per step.

3. Three transformers:

*a*) A Lakon 1 K. W. instrument of four coils, two each in both primary and secondary, built for a primary potential difference of 110 or 220 volts (used by us always at 110), and giving a secondary terminal voltage of 15,000 or 30,000.

*b*) A "type H" General Electric 3.7 K. W. transformer, ratio of transformation 110 to 30,000. This instrument was kindly loaned to us by Professor Rogers, of Lewis Institute, Chicago.

*c*) An Apps induction coil, capable of giving a 12-inch spark from a primary current of 15 amperes. As used in this investigation the "make and break" was cut out, and an alternating current was passed through the primary.

4. To measure the current flowing, the potential difference at the transformer terminals, and the power developed, three Thomson instruments made by the General Electric Co.: (*a*) a watt meter reading to 25 hectowatts (potential limit 150 volts, current limit 25 amperes); (*b*) an ammeter, limit 50 amperes; (*c*) a volt meter, limit 150 volts. By use of a double-throw, double-pole switch the ammeter could be employed at any time to measure the current in the field circuit of the alternator.

5. A condenser built of 7.8 mm. glass plates and pieces of thin sheet brass, 30 cm. wide by 35 cm. long. Assuming the specific inductive capacity of glass to be 6, the capacity of a single elementary section would be probably about 0.0007 microfarads. The combinations generally used were:

| 4 plates giving | about | 0.003 | microfarads |
|---|---|---|---|
| 7 " " " | | 0.005 | " |
| 8 " " " | | 0.006 | " |
| 9 " " " | | 0.007 | " |
| 19 " " " | | 0.014 | " |

The maximum capacity obtainable was about 0.07 microfarads.

As considerable sparking occurred between the elementary sections, the condenser was covered with paraffin. Finally, as the difficulty was not entirely cured, part of the bank of plates, containing the sections of 1, 2, 4, 7, 8, 9, and 19 elements, was placed in a tank filled with transformer oil. This completely prevented sparking.

6. In the discharge circuit of the condenser, in series, *always*, (*a*) an air-gap, and (*b*) the vessel in which the discharge in the liquid occurred; also often (*c*) a coil of self-induction, (*d*) ohmic resistance, in the form of a column of liquid or a fine wire, or (*e*) a second or "accessory" spark-gap in a liquid or in air.

*a*) The air-gap terminals were mounted upon a rotatable device which held terminals of various shapes and sizes.

*b*) The first liquid receptacles were rude affairs. When the importance of the investigation had been fully proven, a more convenient vessel was built—a tank (made of 4 cm. oak) of which the internal dimensions were 17.5×10×10 cm. This was fitted in front with a glass window, and on two sides with pieces of brass pierced with threaded holes through which were screwed brass rods. The inner ends of these were threaded, and to these ends were screwed small caps bearing terminals of the metals to be investigated. The caps could be removed by screwing the brass rods back a short distance. The spark-gap could be adjusted by screwing the rods in or out. An oaken cover was provided for use at higher liquid pressure.

This tank served for a time. Finally a more satisfactory vessel was made from a brass cylinder, 18 cm. deep by 10 cm. in diameter. The use of a metal made insulation necessary. Threaded brass

rods 15 cm. long entered the tank through ebonite cylinders, 3 cm. in diameter and 11 cm. long. The terminal-bearing caps were screwed on as before. Light from the spark reached the spectroscope through a glass window in the front of the tank, and a window in the rear permitted the spark to be seen while running. The tank was supported on an iron tripod, with leveling screws, by means of a hollow shaft, through which ran a drain-tube. A stop-cock at the end of the tube permitted a regulation of the flow of the liquid. A constant level was obtained by means of two efflux tubes set in the side of the tank, either one of which could be used. They gave water-levels of 15 mm. and 56 mm. respectively. The tank cover, which could be screwed on very quickly, was fitted with pressure gauges, influx tube, and a small check-valve to permit the air to escape while the tank was filling. Water was supplied from a pipe directly above the tank. The terminals of the water-gap were adjusted by inserting between them small pieces of brass (0.1, 0.2, 0.3, . . . . 1.0 mm. thick, as the case might be), and then screwing up the movable terminal until it touched the measuring piece lightly. Then the latter was withdrawn. . During extended exposures the length of the gap was adjusted at regular intervals, which ranged in different cases from thirty seconds to five minutes, according to the rapidity of consumption of the metal. It was in this brass tank that most of the experiments described in this section were performed.

c) The self-induction coil was made of No. 16 B. & S. "okonite" covered, copper wire. The wire was wound on a cardboard cylinder in a single layer, and was split into sections of 2, 3, 4, 5, 6, 7, 8, 9, and 9 coils each, followed by nine sections of ten coils each, or 143 turns in all. The coil was 57.5 cm. long by 10.9 cm. in diameter.

d) Ohmic resistance was inserted in the form of either several yards of No. 23 B. & S. copper wire, or a column of liquid in a tube.

e) The accessory spark-gap was formed in various ways (see page 38, item 4).

At this point it may be well to state that in many cases, especially during the latter part of the investigation, the air-spark was rendered more regular and reliable by the use of an electric fan running at about forty revolutions per second. This permitted the use of combinations of the constants of the circuit which, without the fan, would have given intermittent water-sparks requiring very long exposures. So far as is known, the use of the fan makes no difference in the absorption phenomena. This statement is based on several separate experiments. Without the fan only the intermittent disruptive air-sparks cause a luminous discharge in the water; with it every discharge is disruptive. Thus the necessary exposure time is reduced.

B. For collecting the light of the luminous sources a simple and satisfactory arrangement was adopted. All pieces of apparatus were mounted rigidly on a circular table about 180 cm. in diameter, and were so placed that the sparks produced were situated on the circumference of a circle (139 cm. in diameter and eccentric with the table), on the center of which was a plane mirror capable of rotation about a vertical axis in the plane of its face. The light from any source could thus be thrown at once either (1) on a lens which focused it upon the slit of a low dispersion spectroscope—the arrangement used in the preliminary and qualitative investigation, or (2) upon a 22.5 cm. concave mirror (focal length about 2 meters), the position of which was such that an enlarged image was formed upon the slit of a concave grating spectroscope in an adjoining room—the arrangement used in quantitative work (Plate XVI).

C. For analyzing the luminous sources two sets of instruments were employed:

First, for the qualitative work, (a) the solar spectrograph formerly used at the Kenwood Observatory, equipped with a 30° reflecting prism; or (b) the one-prism stellar spectrograph, formerly attached to the 40-inch refractor.

Second, for the quantitative work, a 10-cm. Rowland concave grating, of 14,438 lines to the inch (5,672 to the cm.) and 3m. radius of curvature, giving a spectrum in the first order on the scale of 5.63 tenth-meters per mm. Only the first order was used. A difficulty was presented by the fact

that the ultra-violet and green regions of the spectrum were brilliant, while the violet was extremely weak. Therefore, to render uniform the extended region (28.7 cm.) covered in one exposure, from λ3380 to λ4990, a light cardboard screen, cut so as to expose the less brilliant portion for a greater time, was moved up and down during the exposure in a vertical plane 3 cm. in front of the plate. This motion was produced by a simple device run by a small electric motor. The arrangement worked so well that various screens were cut, suitable for both the comparison and the water spectra of the various metals.[11] It was found that the ordinary slotted metal shutter, turning about a horizontal axis, and used in photographing a comparison spectrum on either side of the water-spark spectrum, gave a decided diffraction effect at the junctions of the two spectra. To remedy this, the old shutter was replaced by two properly slotted metal shutters slipped in from above, one during the comparison spectrum exposure, the other during that of the water-spark. The advantage of this method lies in the fact that the latter form of shutter can be placed very near the plate (i. e., 11 mm.).

D. For measuring the displacements of the lines on the high dispersion plates a Zeiss comparator was employed, of double microscope pattern, giving a magnification of about eight diameters. A single wire was used in the eyepiece. The plates were placed violet left, and four settings were made upon the outer or comparison spectrum, and two upon the inner spectrum; then the same set of measurements was repeated with the plate placed violet right. Duplicate measurements of the same line generally agree to 0.01 tenth-meter. The measurements made upon the plates of the self-induction series are particularly reliable, owing to the fact that the self-induction renders the lines sharper. All of the measurements were made by Dr. Kent. The photographic plates used were Cramer "Isochromatic," and Seed "Gilt Edge" No. 27.

### QUALITATIVE INVESTIGATION WITH LOW DISPERSION

*General behavior of the spark in liquids.*—A few general facts concerning the behavior of the spark in liquids are as follows:

A. In water:

1. Usually, when the water-gap is large (1 mm.), the discharges do not follow each other in rapid succession and are fairly disruptive. With a small water-gap (0.3 mm.) and moderate (5 mm.) air-gap, the discharge is more regular and more disruptive. With small water-gap (0.3 mm.) and large (20 mm.) air-gap, the discharge in water is very regular, and extremely brilliant and disruptive. In all these cases the accessory spark is supposed to be disruptive—inherently so, or rendered so by the action of the fan. When the accessory spark tends to arc, the spark in water either becomes intermittent or does not occur at all.

2. There may be produced a discharge which is fairly brilliant and regular, but so quiet that to hear it the ear must be placed quite near the tank. This discharge occurs when both air- and water-gaps are short (0.2 mm. and 0.5 mm.).

B. In liquids other than water:

1. The phenomena in general resemble those in water. In salt solutions of even as low as 1 or 2 per cent. concentration the spark becomes much fainter, more restricted in size, and often, in extreme cases, consists of merely a quiet, non-disruptive discharge of a reddish tinge. Strong (40 to 60 per cent.) zinc chloride solution produces the same effect; and the broad statement may be made that increasing the conductivity of the liquid produces a weakening of the spark.

2. In methyl alcohol the discharge is extremely brilliant.

3. In kerosene and glycerine a large amount of gas is evolved.

The previous statements refer to iron terminals.

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[11] The intensity of the ultra-violet spectrum falls off rapidly after the spark is started, unless the water in the tank is frequently renewed.

Attention should be called to the fact that titanium and chromium in water give much more brilliant sparks than iron. This is especially true of titanium. The amount of vapor developed with both titanium and chromium is probably great because:

*a*) The spark is large in size.

*b*) The terminals are eaten away rapidly.

*c*) The shattering effect upon the terminals is very great.

These statements apply especially to titanium.

With strong (30 to 60 per cent.) zinc chloride and moderately strong (3 to 4 per cent.) sodium chloride solutions, the ends of the terminals become cup-shaped, suggesting that the discharge occurs principally between the central regions of the terminals. This phenomenon is not met with in the case of the spark in carbon dioxide and air at atmospheric pressure.

*Results with iron electrodes.*—When this investigation was first undertaken, it occurred to us that the character of the spectrum obtained might perhaps be altered by a change in the depth at which the spark took place beneath the surface of the water. Following out this idea, there was taken a series of six plates in which the water-level was varied from 25 cm. to 6 m. above the point of discharge. For a small water depth a wooden tank fitted with one glass side was used; for the greatest depths, there was substituted a glass bottle, provided with a wooden stopper, which was fitted with a tube by means of which the inclosed liquid could be subjected to the pressure of a column of water reaching to the level of the storage tanks of the building. For terminals, pieces of galvanized iron wire 2.3 mm. in diameter were used. The result was a rather remarkable set of plates, which showed a progressive change from a bright line spectrum at low water pressure to an absorption spectrum at the highest pressure. This change suggested further experiments in which capacity, length of water- and air-gap, diameter of water- and air-gap terminals, ohmic resistance, and self-induction in the discharge circuit were severally the variables. The investigation was made qualitatively, and the instruments used were the one prism solar and stellar spectrographs. The results are briefly described below. Table II shows the conditions under which the plates therein given were taken.[12] The conclusions are based, not merely upon these typical plates, but upon a large number of exposures made at various times throughout the investigation. In view of the complexity of the phenomena, and the extreme difficulty of controlling all the conditions that may affect them, some of these conclusions are to be considered as merely probable, rather than as absolutely proved. The original purpose of the investigation (i. e., the bearing of spark spectra in liquids on the theory of temporary stars), and the time at our disposal, did not seem to warrant a complete study of all the phenomena encountered.

1. Change in length of water-gap (Plate 151). A 0.2 mm. gap gives a spectrum marked by strong absorption, while a 1.0 mm. gap gives one of medium absorption. (The use of a very large gap, over 1.0 mm. for instance, will often cause all lines, both bright and dark, to disappear, and will leave only a continuous spectrum.) *Increase of water-gap decreases the absorption.*

2. Change in length of air-gap (Plate 265). There is a marked change from moderate to strong absorption in passing over the range, 1, 10, 20 mm. *Increase of air-gap increases the absorption.*

3. Insertion, or change in length, of second water-gap (in series with first water-gap; Plate 831). A small change toward less absorption appears when the second gap is enlarged from 0.1 to 0.8 mm.—this where tap water is used in the second tank and the discharge is luminous. For the effect when other liquids are used, see pp. 43, 44, 45. *The introduction, or increase in the length, of a second water-gap decreases the absorption.*

4. Change in length of second air-gap (Plates 370, 385, 393). (*a*) When the first air-gap is small—e. g., 5 mm.—an increase in the second from 0 to 24 mm. produces a large increase in absorption; but (*b*) when the first is large—e. g., 19 mm.—a moderate increase—e. g., from 0 to 6 mm.—

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[12] In all the tables the wave-lengths and intensities of the lines are taken from Exner and Haschek's table of the spark spectrum of iron.

in the second produces but a small change. A train of nine equal gaps (formed by pieces of galvanized iron wire, 2.3 mm. in diameter, bent and fastened to a board), giving a total gap of 14 mm. increases the absorption somewhat; and a train of nine, of a total of 36 mm., in combination with a capacity of 0.03 microfarads, a water-gap of 0.1 mm., an air-gap of 19 mm., and no resistance in the transformer circuit, produced the highest absorption obtained by us on any water-spark plate. Very few (only nine) bright lines are shown, and the absorption extends far toward the red; λ4891.62 is absent; λ4920.63 and λ4924.00 are bright lines; and λ4957.80 is reversed. On all our other water plates this last line has appeared bright, although often much shattered and broadened. In general, then, an *increase of the second air-gap, or an introduction of many gaps of moderate length, increases the absorption.*

5. Change in diameter of water-gap terminals. In the preliminary qualitative investigation no plates were taken with the distinct object of showing the effect of change in this constant. Such were taken somewhat later with the large grating, and it was found that an *increase in the diameter of the water-gap terminals increases the absorption.*

6. Change in diameter of air-gap terminals (Plates 824, 825). The terminals used were rounded so that surfaces which were approximately spherical and of diameters 4 mm. (in Plate 824) and 1.5 mm. (in Plate 825) were presented to each other. The resultant difference is small, but unmistakable. With flat ends no difference is apparent. This may be because the discharge in both cases passes between edges. *Increase of diameter of air-spark terminals increases the absorption.*

7. Change of capacity (Plates 286, 289). Many sets of plates were taken at different times, and under various conditions. The effect is evident, but usually small, owing perhaps to the limited range of capacity at our disposal (0.003 to 0.07 microfarads). *Increase of capacity increases the absorption.*

8. Change in temperature of the liquid (two sets of plates, 799 to 801 and 806 to 808). In the first set no particular care was taken to have the kind of water used in the three cases precisely the same. In the second set water was cooled by immersing ice in it; small pieces were left in the spark tank during exposure; and then the same water was filtered through cotton and heated to higher temperatures. The liquid used was thus practically the same throughout the set. The temperatures employed in this second case were 174°, 72°, and 45° F. *Both sets agree in giving a small increase of absorption with decreasing temperature.*

9. Change of self-induction in the discharge circuit (Plates 644, 646). The spark under water is in all cases extremely sensitive to self-induction. Even two or three turns of the self-induction coil previously described will, under certain conditions, produce a change in the absorption, and the whole coil of 143 turns changes a high-absorption spectrum almost completely to a bright-line spectrum (in the violet and ultra-violet). *Increase of self-induction in the discharge circuit decreases the absorption.*

10. Change of ohmic resistance in the discharge circuit (Plates 283, 284). The insertion, non-inductively, of 57 feet of No. 23 B. & S. copper wire produced a spectrum marked by less absorption than that obtained without such ohmic resistance. *Insertion of non-inductive resistance decreases the absorption.*

11. Change of resistance in field circuit of alternator (Plates 464, 466). By moving the arm of the field rheostat it was apparent that there was a point at which the spark was both more brilliant and more disruptive. At this point the circuit acted as though it were in resonance. Two exposures were made on each of the two plates, on 464 at resistances 0 and 39 ohms—"resonance" at 39; and on 466 at 34.5 and 56.5 ohms—"resonance" in this case being at the point of less resistance, namely, 34.5 ohms. In both cases distinctly greater absorption is shown at "resonance," and the watt meter there registers greater energy. *Therefore the absorption is increased by an approach to a condition of "resonance," whether this process involves an increase or decrease in field circuit resistance.*

12. Change of resistance in primary circuit of transformer (Plate 262). *A decrease of resistance in the primary circuit of the transformer produces increased absorption.*

13. Change of transformer (Plate 828). On the plate cited the Apps induction coil spectrum is marked by more absorption than that given by the Lakon transformer connected for 15,000 volts. It cannot be definitely stated that this will always be the case. Under the conditions used in obtaining Plate 828 the induction coil produced a more regular, brilliant, and disruptive spark.

In the first published note regarding the results obtained with the spark in liquids it was stated that a bright line spectrum, with no reversals, was obtained with the iron spark in water when the Apps coil was used. This was indeed the case. But the constants of the circuit, Plate 227, were such as would have properly produced an emission spectrum even if the Lakon transformer had been used. The diameter of the water-gap terminals was small (1 mm.), the capacity was 0.006 microfarads, the water level was 26 mm., the fan was not running, and the water-spark was short; the air-spark was rather long, but its terminals were small, and the spark was weak.

From paragraphs 11, 12, and 13 it may be seen that the phenomenon under discussion is probably not merely a function of the electric constants of the circuit on the discharge side of the condenser (the degree of absorption being determined only by these and the capacity), but depends also upon the transformer used and the current flowing in the external and field circuits of the alternator. It may be that other electrical constants of the circuit, as yet unknown, also have an influence upon the character of the spectrum obtained.

14. After several sets of experiments dealing with the problems just presented had been made, it appeared desirable to repeat the original water-pressure series, using the improved apparatus, the brass tank previously described. We were surprised to find that the water-pressure effect could generally be obtained to only a small degree, and under some conditions did not appear to exist at all. It was only after many attempts, made at different times throughout the investigation, that the conditions which are conducive to a distinct change were discovered.

We can make no very positive statements regarding the water-pressure effect, but it will probably appear whenever the constants of the circuit are such that (1) at low water pressure the air-spark burns rather quietly (but with sufficient disruption, of course, to cause a luminous discharge across the water gap), and is characterized by a red or pink color; and (2) at high pressure the reaction of the water-spark will be such that the air-spark burns very disruptively and possesses a violet color. In obtaining such a state of the circuit, the following considerations are of value:

1. The water-gap should be short, from 0.1 to 0.3 mm. The diameter of the water-gap terminals ordinarily used was 2.3 mm. (no study of the bearing of a change of this constant upon the pressure effect was made).

2. The air-gap should be short, 0.5 to 1.0 mm.; and the diameter of the terminals small, e. g., 0.8 mm.

3. A certain small amount of self-induction in the discharge circuit (e. g., 2 turns of the coil) is favorable, but not essential. Similarly, a small amount of ohmic resistance is advantageous.

4. The capacity must be large enough (e. g., 0.005 to 0.007 microfarads) to cause sufficient disruption over the air-gap to produce a luminous discharge in water.

In this connection it may be stated that the use of the fan upon the air-gap is not prohibitive of the effect.

5. The conditions of the air of the room possibly have an effect. In a cool, dry atmosphere the air-spark seems to burn quite disruptively; in a warm, moist atmosphere, quietly; and, although all the electrical constants of the circuit may be identical and the water-level be the same, the spectra may differ considerably. The dry air tends to produce an absorption spectrum; the moist air, a spectrum marked by more bright lines.

The conditions under which the original set of plates were taken chanced to be quite similar to those given above. It is rather odd that this water-pressure effect which, of all the phenomena investigated, proved the most difficult to reproduce, should have been encountered first.

The above data suggest that an increase of water pressure produces increased absorption in the spectrum primarily by altering the electrical conditions of the circuit, rather than by changing the physical condition of the water-spark, by creating a greater amount of absorbing vapor, or massing it more closely around the spark. To settle this question, the following experiment was performed. Two tanks, the brass and the wooden, were placed in series, and the circuit arranged for as low absorption as possible consistent with good running. The conditions were as given in Table II, Plates 796–98 and 809–13. A complete set of plates is schematically as follows:

PLATE A, EXPOSED TO SPARK IN BRASS TANK

Exposure No. 1:  Level of water in brass tank 15 mm.; in wooden tank 15 mm.
Exposure No. 2:  Level of water in brass tank 6 m.; in wooden tank 15 mm.

PLATE B, EXPOSED TO SPARK IN WOODEN TANK

Exposure No. 1:  Level in brass tank 15 mm.; in wooden tank 15 mm.
Exposure No. 2:  Level in brass tank 6 m.; in wooden tank 15 mm.

In both A and B greater absorption is shown when the spark in the brass tank is subjected to the pressure of 6 m. of water. The experiment was repeated several times under slightly different conditions. In all the spectra taken from the oak tank spark there appears a difference in the direction: greater pressure more absorption; while the difference in the brass tank spectrum is not always noticeable, but, when apparent, it is in the same direction. The experiment is difficult to perform because of the many and delicate adjustments to be made.

This seems to indicate that the effect, if genuine, is electrical, for increased pressure in the brass tank produces increased absorption in the wooden tank.

*Results with electrodes of metals other than iron.*—To discover whether or not this progressive absorption, following suitable changes of electrical conditions, was a general phenomenon and not one peculiar to iron alone, a series of plates was taken with other metals: for every metal one or more plates containing in most cases two exposures, one given under low absorption conditions and another under high.

Manganese, antimony, bismuth, tin, gold, calcium, silver, nickel, cobalt, and titanium follow the rule given for iron, and their spectra present no marked peculiarities.

Aluminium, besides following the general rule, presents the interesting phenomenon of double reversal. Three exposures, under conditions such that a progressive change of absorption should appear, were made upon one plate (No. 445). In all three spectra the two chief aluminium lines, $\lambda\,3944$ and $\lambda\,3962$, appear as broad absorption lines. In the lowest absorption spectrum these two lines have at their extremities faint but fine bright lines. In the medium absorption spectrum these bright lines are very intense, and extend over the whole length of the absorption line; in the spectrum taken under the highest absorption conditions, they are absent entirely. Similar dark and bright lines are present in the iron spectrum, but the problem of their behavior has not been studied fully enough to warrant any statement concerning them.

Lead ($\lambda\,4058$) and cadmium ($\lambda\,3611$) show changes which, as far as investigated, are similar to those of iron.

Magnesium shows the flutings between $\lambda\,5100$ and $\lambda\,5200$ (Plate 352), and it is in them that the progressive absorption is most clearly apparent. Under high absorption conditions they appear composed of clearly marked dark lines. On the other hand, $\lambda\lambda\,3830$, $3832$, and $3838$ remain very sharp bright lines throughout the series of exposures.

## TABLE II

### Low Dispersion or Qualitative Plates: Physical and Electrical Conditions during Exposures

| NUMBER OF PLATE | LENGTH OF GAPS IN MM. Water | Air | Second Water | Second Air | DIAMETER OF TERMINALS IN MM. Water | Air | Second Water | Second Air | METAL AND SHAPE Water* | Air | Second Water | Second Air | Field Circuit Resistance in Ohms† | Transformer Circuit Resistance in Ohms† | Capacity in Microfarads | Self-Induction in Number of Turns of Coil | Fan Running | Water Level in mm. | Transformer Used | REMARKS§ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 151 | 0.2, 1.0 | 6 | ..... | : | 2.3 | 0, 5+3 | : | : | Fe Wire | Bessem'r Steel | ..... | ..... | 0 | 4 | 0.0058 | 0 | No | 20 | Lakon 30,000 | |
| 227 | Small | 12+ | ..... | : | 1.0 | 2.3 | : | : | Bessem'r Steel | " | ..... | ..... | 0 | : | 0.0058 | 0 | " | 26 | Apps | |
| 262 | 0.3 | 20 | ..... | : | 2.3 | 2.3 | : | : | ..... | " | ..... | ..... | 10 | 4.0 | 0.0058 | 0 | " | 26 | Lakon 15,000 | |
| 265 | 0.2 | 1.10.20 | ..... | : | 2.3 | 2.3 | : | : | ..... | " | ..... | ..... | 0 | 4 | 0.0058 | 0 | " | 26 | " | |
| 283 284 | 0.2 | 20 | ..... | : | 2.3 | 2.3 | : | : | ..... | " | ..... | ..... | 0 | 4 | 0.0058 | 0 | " | 26 | " | In 283 no resistance in discharge circuit. In 284 57 feet of No. 23 copper wire in discharge circuit. |
| 286 289 | 0.2 | 2 | ..... | : | 2.3 | 1+4 | : | : | Mg | " | ..... | ..... | 0 | 4 | 0.0058 0.0597 | 0 | " | 26 | " | |
| 352 | .1 to .5 .4 to .5 .9 to .95 | 19 | ..... | : | 2.1 | 4 | : | : | " | " | ..... | ..... | 22 | 4 | 0.0058 | 0 | " | 26 | |
| 370 385 393 | 0.3 0.5 0.1 | 19 5 19 | ..... | 3.6 14 36 | 2.3 2.3 2.3 | 4 2.3 4 | : | 5 2.3 2.3 | Bessemer Steel | " | ..... | Bess. St. Fe Wire | 45 37 0 | 4 4 0 | 0.0058 0.0058 0.0280 | 0 | " | 26 | " | 14 mm. gap, formed of train of 9 gaps of 1 to 3 mm. each. 36 mm. gaps formed of 9 gaps. |
| 445 | 0.5 0.3 0.1 | 2 10 19 | ..... | : | 2.1 | 2 | : | : | Al | Brass | ..... | ..... | 0.39 56.5.34.5 | 6 4 2 | 0.0014 0.0058 0.0182 | 0 | " | 26 | " | |
| 464 466 | 0.3 0.2 | 10 15 | ..... | : | 2.3 2.3 | 2.3 2.3 | : | : | Bessemer Steel | " | ..... | ..... | 0 | 4 4 | 0.0058 0.0029 | 0 | " | 26 | " | "Resonance" at 26. " " 23. |
| 644 646 | 0.2 | 10 | ..... | : | 2.3 | 4 | 2.3 2.3 | : | " | Bessem'r Steel‡ | Bessem'r Steel | ..... | 0 | 4 | 0.0066 | 143 0 | Yes " " | 56 | Lakon 30,000 | A second exposure made at 8.5 lbs. pressure |
| 796 797 798 | 0.1 0.1 | 1 1 1 | 0.1 0.1 0.1 | : | 2.3 2.3 2.3 | 4+2.3 4 4 | : | : | Fe Wire | Fe Wire | ..... | ..... | 0 0 0 | 4 4 4 | 0.0014 | 0 | No | 15 15 15 | " | 10 " 10 |
| 799 800 801 806 807 808 | 0.3 | 1.0 | ..... | : | 2.3 | 0.8 | : | : | " | Brass | Bessem'r Steel | ..... | 0 | 4 | 0.0014 | 0 | No | 15 | " | Water at 140° F. " 76 " 46 " 45 " 72 " 174 |
| 809 810 811 812 813 | 0.1 0.1 0.1 0.1 | 1.0 1.0 1.0 1.0 1.0 | ..... | : | 2.3 | 4 4 4 4 4 | 2.3 2.3 2.3 2.3 2.3 | : | Bessem'r Steel | Bessem'r Steel‡ | Bessem'r Steel | ..... | 0 0 0 0 0 | 4 | 0.0051 | 0 0 2 2 2 | No Yes " " " | 15 | " | Exposures made on brass and oak tanks as described on p. 41. |
| 824 825 | 0.3 | 2 | ..... | : | 2.3 | 4 1.5 | : | : | " | Fe Wire | ..... | ..... | 0 | 4 | 0.0066 | 0 | " | 15 | Lakon 15,000 | |
| 828 | 0.5 | 3 | ..... | : | 2.3 | 4 | : | : | " | " | ..... | ..... | 0 | 6 | 0.0066 | 0 | " | 15 | Apps Lakon 15,000 | |
| 831 | 0.5 | 5 | 0.1, 0.8 | : | 2.3 | 4 | 2.3 | : | " | " | Bessem'r Steel | ..... | 0 | 6 | 0.0066 | 0 | " | 15 | Lakon 15,000 | |

* Flat ends always used.    † Over and above resistance of field coils of alternator and primary winding of transformer respectively.    ‡ Rounded ends.

§ The low dispersion plates from Nos. 1 to 553 (inclusive) were taken with the solar spectrograph, and those from Nos. 554 to 831 (inclusive) were taken with the stellar spectrograph.

*Results with liquids other than water.—*

1. At the beginning of this investigation the question was raised whether or not the character of the iron spectrum might depend upon the nature of the liquid in which the discharge took place. Moreover, it appeared probable that the electrical conductivity might enter as a determining factor. Naturally, therefore, non-conducting liquids, salts of different conductivities, and various concentrations of the same salt were tried.

2. Three sets of plates were taken, the members of each set being comparable among themselves. The results may be summarized in the following tables, in which the conductivity is calculated (by reference to Landolt and Börnstein's tables[13]) from either the known concentration or the measured resistance.[14]   The liquids are arranged in groups in order of decreasing absorption—e. g., in Table III, group "$a_1$" shows the greatest absorption, and group "$d_1$" the least.   The groups of the three tables are not related.

### TABLE III*

Constants: $G=0.3$; $g=19$; $D=2.3$; $d=4$; $c=0.006$; $h=26$

| Liquid | Concentration | Conductivity | Group |
|---|---|---|---|
| Gasoline........................ | .... | 0 | $a_1$ |
| Glycerine....................... | .... | 0 | |
| Benzine ........................ | .... | 0 | |
| NaOH........................... | 0.8 % | $3,300. \times 10^{-9}$ | $b_1$ |
| KOH............................ | 1.2 | $3,300. \times 10^{-9}$ | $c_1$ |
| Distilled water.................. | .... | $10 \times 10^{-9}$ | $d_1$ |

*The abbreviations at the head of each table have the following significance:
$G$ stands for length of  primary  gap in millimeters.
$g$   "    "    "    " secondary  "    "    "
$D$   "    "  diameter of  primary  terminals in millimeters.
$d$   "    "    "    " secondary    "    "    "
$c$   "    "  capacity in microfarads.
$h$   "    "  distance from terminals to surface of liquid in millimeters.

### TABLE IV

Constants: $G=0.2$; $g=10$; $D=2.3$; $d=4$; $c=0.006$; $h=26$

| Liquid | Concentration | Conductivity | Group |
|---|---|---|---|
| Methyl alcohol................... | .... | 0 | $a_2$ |
| Kerosene ...... ................. | .... | 0 | $b_2$ |
| BaCl ........................... | 19% | $11,900. \times 10^{-9}$ | $c_2$ |
| NaCl ......... ................. | 1 | $1,380. \times 10^{-9}$ | $d_2$ |
| NH₄OH.......................... | 3 | $900 \times 10^{-9}$ | $e_2$ |
| NH₄OH.......................... | 25 | $1 \times 10^{-9}$* | $f_2$ |
| NH₄OH.......................... | 50 | ? | $g_2$ |
| Tap  water...................... | .... | ? | $h_2$ |

*Extrapolated from data given by Landolt and Börnstein.

### TABLE V

(For constants of the circuit see below, paragraph 5)

| Liquid | Concentration | Conductivity | Group |
|---|---|---|---|
| NaCl ............. ............. | 8% | $9300 \times 10^{-9}$ | $a_3$ |
| NaCl ........................... | 4 | $5270 \times 10^{-9}$ | $b_3$ |
| NaCl ........................... | 1 | $1360 \times 10^{-9}$ | $c_3$ |
| NaCl ........................... | ⅛ | $186 \times 10^{-9}$ | $d_3$ |

[13] In Landolt and Börnstein's tables the conductivity of a column of mercury of specific dimensions is taken as unity.
[14] Determined by Kohlrausch's alternating current method.

3. At this point it may be well to note that our first plates taken with glycerine showed a bright-line spectrum devoid of all absorption lines, whereas other non-conducting liquids, such as gasoline and benzine, produced a spectrum marked by high absorption. It had been noticed, however, that with this viscous liquid the bubbles of gas formed by the discharge were both large and slow in rising from the terminals; and it seemed probable that after the first spark the discharge took place in the gas. This would explain the bright-line spectrum. To avoid this difficulty, the switch in the primary circuit of the transformer was closed for as short a time as possible, and the bubbles allowed to rise out of the way between each set of sparks. The result was a spectrum marked by as high absorption as those given by gasoline or benzine.

From the data given in these three tables (III, IV, and V), it is clear that the electrical conductivity is not the sole determining factor. The character of the liquid has an influence.

4. To study the electrical effect upon the circuit and differentiate it from any other possible effect, the accessory tank, which we shall call $T_1$ (that used in connection with the hydrostatic pressure effect in the case of pure water; see p. 38.), was joined in series with the original tank, $T_0$, and the air-gap. Various liquids were placed in $T_1$, and their effect upon the spectrum given by the ordinary arrangement (iron terminals and tap water) in $T_0$ was studied.

Here a distinction must be made between two sets of phenomena in $T_1$. In the first the discharge passes disruptively, and a spark results; while in the second the current is conducted without disruption and no sparks appear.

5. *First*, a disruptive discharge in $T_1$. The order is:

> 1 per cent. NaCl solution, showing greatest absorption in $T_0$
> 0.5 per cent. NaCl solution, showing less absorption in $T_0$
> Tap water, showing least absorption in $T_0$

The constants of the circuit here were $G=0.2$; $G'=0.2$; $g=14$; $c=0.012$, where $G'$ stands for the length (in mm.) of the spark-gap in the accessory tank. Moreover, an increase of the gap in this accessory tank tends to produce a bright-line spectrum in $T_0$. But when glycerine, gasoline, or "18 to 1" transformer oil[15] are used in $T_1$, an increase in $G'$ increases the absorption in $T_0$; and even when $G'$ is small, the absorption is a little greater than when no accessory tank is introduced into the circuit. In this respect the introduction of this accessory tank resembles in its effect that of a second air-gap (the influence of which has been discussed on p. 38).

Again, *second*, a non-disruptive discharge in $T_1$:

A 4 per cent. solution of NaCl gave a spectrum marked by far greater absorption than did tap water. The constants of the circuit were: $G=0.2$; $G'=10$; $g=19$; $c=0.006$.

Moreover a 10 per cent. solution of NaCl produced a spectrum which showed much less absorption than that given where a thick wire replaced the tank $T_1$. The constants of the circuit were: $G=0.2$; $G'=22.5$; $g=19$; $c=0.006$.

The order is:

> *a*) Thick wire (no accessory tank), greatest absorption in $T_0$
> *b*) 4 per cent. or 10 per cent. NaCl solutions in $T_1$, less absorption in $T_0$
> *c*) Tap water in $T_1$, least absorption in $T_0$

Therefore the introduction of a salt solution (or tap water) in this manner gives results similar to those obtained by introducing ohmic resistance or self-induction in the discharge circuit, and the longer the gap $G'$, the greater the tendency toward a bright-line spectrum.

The conclusions to be drawn from the data here given are:

*a*) That the influence of the liquid in the tank $T_1$ upon the spectrum given in $T_0$ cannot be chemical—it must be electrical.

[15] Of specific inductive capacity 18.

*b*) That in the case of a conducting liquid like a NaCl solution, whether the spark be passing or not, an increase in the conductivity of the liquid in $T_1$ produces an increase in absorption in the spectrum of $T_0$. The effect thus corresponds with the reduction of ohmic resistance in a metallic circuit (p. 39).

*c*) That the introduction of a non-conducting liquid in $T_1$ tends to increase the absorption in $T_0$, and an increase of $G'$ produces an increase in absorption in $T_0$. (See the effect of increasing an auxiliary air gap, p. 39.)

6. Again, to eliminate the electrical effect, a series of plates was taken in the following manner: Tank $T_0$ was filled with tap water and $T_1$ with a 1 per cent. salt solution. The constants were. $G = 0.2$; $G' = 0.2$; $g = 10$; $c = 0.006$, which arrangement gave a spark in both tanks. The depth of each liquid was 26 mm. The spectrum given by tank $T_0$ was photographed; then the central mirror was turned, and upon the same plate was placed the spectrum of $T_1$. To confirm the results this plate was duplicated. Then the liquids were interchanged, $T_1$ being filled with tap water and $T_0$ with the 1 per cent. salt solution—this to eliminate the possibility of an effect due to a possible difference of some nature in the tanks. Exposures of both sparks were made as in the first series, and in this case three identical plates were taken. In all five plates the NaCl solution gives the spectrum marked by the greatest absorption. From this we must conclude that the influence of the salt solution must enter in determining the absorption in at least one other way than that of changing the electrical constants of the circuit, for the two exposures on any one plate were taken under the same electrical conditions. We are forced to believe that there is a chemical effect, created by the salt solution upon the iron.

7. Again, to separate the effect of quantity of salt or concentration from that of conductivity, it was desirable to obtain a liquid which has the same conductivity at two different concentrations. Zinc chloride fulfilled this requirement. Its conductivity-concentration curve reaches a maximum at approximately 30 per cent., and the conductivities of a 4 per cent. and 58 per cent. solution are almost identical. The more concentrated solutions were somewhat viscous and presented the same difficulty as glycerine. But the single-spark method of exposure removed the difficulty.

Starting with a 58 per cent. solution two series of plates were taken, each series representing spectra given at four points on the curve. Each exposure was made in duplicate. Both sets gave the same results, and exposures made under similar conditions agreed satisfactorily. The results may best be shown by the study of a set of nine lines which are most susceptible of change under the conditions employed.

The constants were: $G = 0.3$ for series No. 1 and 0.4 for series No. 2; $g = 19$; $D = 1$; $d = 4$; $c = 0.012$. The accompanying table (VI) explains itself.

After dilution at point No. 2 on the curve (see Fig. 1), the solution gradually clouded with a white precipitate, and the concentration changed, passing around the curve. After a short time the solution was filtered, and exposure made at point No. 3. The concentration was calculated from the measured resistance by use of Landolt and Börnstein's tables, and also (until precipitation) from the known dilution.

The natural conclusion is that the amount of the salt present has a marked influence apart from the conductivity. In fact, from the different rates of change—slow between points No. 1 and No. 2, and rapid between No. 2 and No. 3, and between No. 3 and No. 4—and by reference to the conclusions drawn in paragraph 5, the following deductions are rendered probable:

*à*) That an increase in the quantity of the salt present tends to increase the absorption chemically; and

*b*) That an increase in the conductivity of the solution tends to increase the absorption electrically. These two tendencies are in opposition on the first third of the curve, the second is approximately eliminated in the second part, and they act together in the third.

TABLE VI

ZINC CHLORIDE SOLUTION: ABSORPTION AS A FUNCTION OF CONDUCTIVITY AND CONCENTRATION

| Point on Curve | No. of Lines Appearing as Full Absorption Lines | No. of Lines Appearing as Absorption Lines with Bright Edges | No. of Lines Appearing as Bright Lines | Resistance* of Solution in Ohms | Conductivity† $\times 10^9$ | Percentage Concentration of Solution |
|---|---|---|---|---|---|---|
| FIRST SERIES: LIQUID GAP = 0.3 MM. | | | | | | |
| 1 | 5‡ | 3‡ | 1 | 8.30 | 4032 | 58 |
| 2 | 0 | 8 | 1 | 4.55 | 7400 | 45 |
| 3 | 0 | 5 | 4 | 4.65 | 7200 | 12 |
| 4 | 0 | 3 | 6 | 8.30 | 4032 | 4 |
| SECOND SERIES: LIQUID GAP = 0.4 MM. | | | | | | |
| 1 | 0‡ | 8‡ | 1 | 8.30 | 4032 | 58 |
| 2 | 0 | 8 | 1 | 4 55 | 7400 | 45 |
| 3 | 0 | 5 | 4 | 4.65 | 7200 | 12 |
| 4 | 0 | 3 | 6 | 8.30 | 4032 | 4 |

*Measured by Kohlrausch's method.

†As given by Landolt and Börnstein. Standard chosen is mercury.

‡It will be noticed that the length of liquid gap was 0.4 mm. in the second series and 0.3 in the first. This perhaps explains the presence of five full absorption lines and three absorption lines with bright edges in the first set, while no full absorption lines, but eight with bright edges, appear in the second. At highest concentration the length of gap appears to be particularly influential in producing a change in absorption.

8. The general conclusions which seem to follow from the data given in the seven preceding paragraphs are as follows:

*a*) That non-conducting liquids (like an auxiliary air gap) increase the absorption of the spectrum given by the terminals immersed in them principally, if not entirely, by reason of their influence upon the conditions of the electric circuit.

*b*) That conducting liquids increase the absorption somewhat by means of their electrical influence, but mainly by the chemical action upon the terminals. This conclusion is in harmony with the results of Bredig and Haber, who have found that in high potential electrolysis, and with metal arcs and sparks under water, the presence of alkali causes more rapid pulverization of the electrodes.[16]

To illustrate the changes in the spark between iron electrodes in water under different electrical conditions, and in sodium chloride solutions of different concentrations, enlargements of plates obtained at low dispersion were made and arranged in order of increasing absorption. Plate XVII[17] represents the result. All the changes apparent relate to the iron lines of the spark, and not to lines due to substances present in the particular liquid employed. It should be stated that as subsequent experiments never showed such marked increase of absorption as these salt solutions seemed to produce, other causes, unknown to us, may have enhanced the effect in these photographs.

No great weight can be ascribed to the conclusions of this section of our paper. The importance of this work did not seem sufficient to warrant the expenditure of the time required to clear up all doubtful points.

### QUALITATIVE INVESTIGATION WITH HIGH DISPERSION

The preceding results were obtained with spectroscopes of low dispersion, capable of showing the general character of the absorption phenomena in a satisfactory manner, but not adapted for a precise study of the shifts of the lines under different conditions, or of the details of the absorption phenomena. This work was accordingly undertaken with the concave grating spectroscope described

[16] *Chemische Berichte*, Vol. XXXI (1898), p. 2741; *Zeitschrift für angewandte Chemie*, 1898 p. 951; *Zeitschrift für Elektrochemie*, Vol. IV, pp. 514, 547.

[17] Previously published in the *Astrophysical Journal*, Vol. XV, No. 2, (March, 1902.)

on page 36.   A 15 cm. grating of 6.5 m. radius was employed for various special studies, but the greater part of the work was done in the first-order spectrum with a 10 cm. grating of 3 m. radius. Suitable shutters made possible the method of double exposure of the comparison spectrum.   Generally a spark in air was exposed first and placed upon the outer portions of the photographic plate; then the spectrum of the spark in the liquid was thrown upon the center of the plate; and finally, in the third exposure, a spark in air was superposed upon the first.[18]
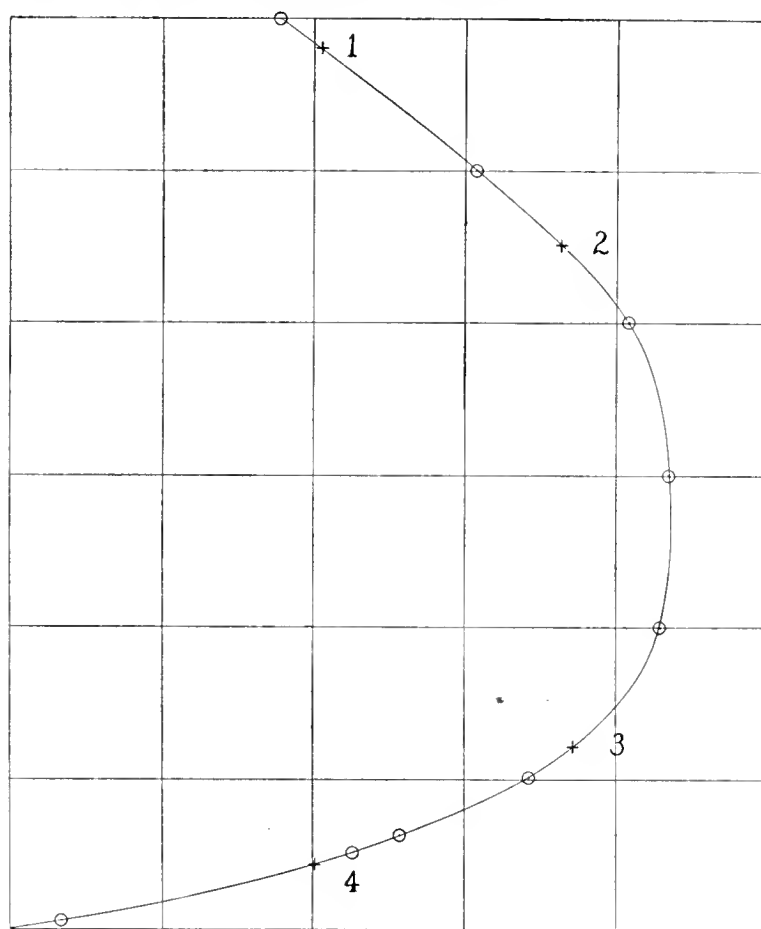


Fig. 1

| Percentage Concentration | Conductivity (compared with Mercury) |
|---|---|
| 0.64 | $780 \times 10^{-9}$ |
| 5.00 | 4520 |
| 6.35 | 5178 |
| 10.00 | 6800 |
| 20.00 | 8530 |
| 30.00 | 8660 |
| 40.00 | 7900 |
| 50.00 | 5890 |
| 60.00 | 3450 |

[18] In all cases the constants of the electrical circuit used to give the comparison spectrum were as follows:
    Length of spark, 4 mm.; size of Bessemer steel terminals, 2×5 mm.; no field resistance (other than that in the field coils themselves); field current, about 4.5 amperes; transformer resistance, 4 ohms when the General Electric transformer was used, and 3 ohms with the Lakon transformer; power, 90 watts; current, 23 amperes; potential at primary terminals of transformer, 3 volts; and capacity, 0.014 microfarads·

In discussing the results obtained on the high dispersion plates, we may consider them in the following order:

A. Details of absorption phenomena and types of lines represented on the plates.

B. Absorption phenomena produced by changing the constants of the circuit.

C. Shifts of the lines produced by changing the constants of the circuit.

D. Shifts of the lines in a solution of sodium chloride.

E. Spectrum of the rotating arc in liquids.

A. *Types of lines.*—Reference has already been made to the various types of lines distinguished by Wilsing, Lockyer, and Konen. On our high-dispersion photographs ten distinct types occur in the spectrum of iron as follows:

(1) Narrow emission line.

(2) Broad, fairly symmetrical, emission line.

(3) Broad emission line, diffuse toward the red.

(4) Simple absorption line.

(5) Absorption line superposed fairly symmetrically on broad emission line.

(6) Absorption line superposed on broad emission line, which is strongest on red side.

(7) Similar to (6), but with the violet component of the emission line lacking.

(8) Narrow emission line, superposed symmetrically on absorption line; a combination of (1) and (4).

(9) Absorption line, with narrow emission line through its center, superposed fairly symmetrically on broad emission line: a combination of (1) and (5).

(10) Absorption line, with narrow emission line through its center, superposed on broad emission line, which is strongest on red side: a combination of (1) and (6).

These several types are illustrated in Plate XVIII. In studying the shifts of the lines under various conditions, it is of importance that the corresponding type should be recorded in each case.

It is, however, difficult to classify lines of types (5), (6), and (7), because the difference between (5) and (6), and between (6) and (7) is so slight. Prolonged exposure may bring out a violet component of the line which at normal exposure appeared to be of type (7). The differences between the three types depend upon (a) the width of the basal emission line, (b) the width of the absorption lines, and (c) the relative positions of the maxima of emission and absorption. From the data at hand it is impossible to divide these lines into three classes with absolute precision. The shifts of the emission components of the lines of types (5), (6), and (7) were measured only in the case of type (7). With compound lines, particularly those of types (6) and (7), as both Wilsing and Lockyer have pointed out, a setting on the middle of the displaced bright line does not give the true displacement, on account of the presence of the absorption line. Again, it is important to ascertain, in studying the displacement of the bright lines, whether we are dealing with a case of unsymmetrical widening toward the red, where, as Kayser[19] has so conclusively shown, there may be no real shift of the line, or whether there is a true displacement of the line as a whole.

It should perhaps be noted that lines of types (8), (9), and (10) cannot be explained on the assumption of mere double exposure of the plate, producing a superposition of the comparison spectrum of the spark in air upon the spectrum of the water-spark. For the negatives which show lines of these types also have upon them strong lines of types (5) and (6), in which any chance superposition would be at once betrayed. We seem to be dealing here with true double reversals. The interest in these lines is increased by the fact, which Kayser has pointed out, that true cases of double reversal are difficult to produce at will by ordinary laboratory methods. In the present case there is no difficulty in obtaining such lines as often as may be desired.

[19] *Handbuch der Spectroscopic*, Vol. II, p. 366.

## TABLE VII

### High Dispersion or Quantitative Plates: Physical and Electrical Conditions During Exposures

| No. of Plate | Length of Gaps in CM. Liquid | Length of Gaps in CM. Air | Diameter of Terminals in CM. Liquid | Diameter of Terminals in CM. Air | Metal and Shape Liquid | Metal and Shape Air | Field Circuit of Alternator Resistance in Ohms* | Field Circuit of Alternator Current in Amperes | Primary Circuit of Transformer Resistance in Ohms* | Primary Circuit of Transformer Power in Watts | Primary Circuit of Transformer E.M.F. in Volts† | Primary Circuit of Transformer Current in Amperes | Capacity in Micro-farads | Discharge Circuit of Condenser Self-Induction in Number of Turns | Discharge Circuit of Condenser Fan Running | Liquid Medium | Level of Spark above Liquid in MM. | Speed of Alternator in Revolutions per Minute | Exposure in Minutes | Transformer Used |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 604 | 0.3 | 5 | 1.0 | 4 | Fe, flat | Fe, round | 0 | 5.3 | 4 | 290 | 36 | 12.1 | 0.0029 | 0 | Yes | Tap water | 56 | 1570 | 18 | General Electric |
| 697 | 0.3 | 5 | 1.6 | 4 | " | " | 0 | 4.5 | 4 | 290 | 19 | 17.4 | 0.0029 | 0 | " | " | 56 | 1570 | 18 | " |
| 603 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | 5.3 | 4 | 100 | 31 | 15.4 | 0.0029 | 0 | " | " | 56 | 1715 | 24 | " |
| 605 | 0.3 | 5 | 4.0 | 4 | " | " | 0 | 3.3 | 4 | 280 | 34 | 14.4 | 0.0029 | 0 | " | " | 56 | 1645 | 20 | " |
| 659 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 3.5 | 3 | 400 | 31 | 22.0 | 0.0066 | 143 | " | " | 56 | 1945 | 20 | " |
| 651 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 5.0 | 3 | 280 | 32 | 23.5 | 0.0066 | 104 | " | " | 56 | 1815 | 14 | " |
| 650 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 4.5 | 3 | 410 | 31 | 23.0 | 0.0066 | 54 | " | " | 56 | 1850 | 12 | " |
| 658 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 3.0 | 3 | 530 | 37 | 23.5 | 0.0066 | 27 | " | " | 56 | 1880 | 10 | " |
| 646 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 3.0 | 3 | 480 | 27 | 25.0 | 0.0066 | 14 | " | " | 56 | 1880 | 7 | " |
| 665 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 4.0 | 3 | 550 | 33 | 25.0 | 0.0066 | 0 | " | " | 56 | 1820 | 7 | " |
| 666 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 4.0 | 3 | 480 | 27 | 25.5 | 0.0066 | 14 (62 ft. Cu wire) | " | " | 56 | 1880 | 7 | " |
| 716 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 4.7 | 3 | 530 | 33 | 24.5 | 0.0066 | 27 | " | " | 56 | 1880 | 6 | " |
| 658 | 0.3 | 10 | 2.3 | 4 | " | " | 0 | 3.0 | 3 | 530 | 37 | 23.0 | 0.0066 | | " | " | 56 | 1840 | 10 | " |
| 672 | 0.3 | 1 | 2.3 | 2.3 | " | Brass, flat | 22.5 | 3.0 | 3 | 130 | 9 | 23.0 | 0.0205 | 0 | " | " | 56 | 1890 | 10 | General Electric 15000 |
| 702 | 0.3 | 1 | 2.3 | 2.3 | " | " | 22.5 | 3.5 | 3 | 190 | 11 | 22.5 | 0.0066 | 0 | " | " | 56 | 1885 | 30 | Lakon 15000 |
| 704 | 0.3 | 1 | 2.3 | 2.3 | " | " | 22.5 | 4.0 | 3 | 160 | 11 | 20.8 | 0.0029 | 0 | " | " | 56 | 1925 | 65 | Lakon 30000 |
| 712 | 0.3 | 1 | 2.3 | 2.3 | " | " | 22.5 | 4.0 | 3 | 170 | 11 | 22.8 | 0.0029 | 0 | " | " | 56 | 1940 | 50 | |
| 685 | 0.3 | 15 | 2.3 | 2.3 | " | Fe, round | 39 | 3.0 | 0 | 440 | 32 | 21.5 | 0.0066 | 0 | " | " | 56 | 1790 | 7 | General Electric |
| 702 | 0.3 | 1 | 2.3 | 2.3 | " | " | 40.5 | 5.0 | 3 | 190 | 11 | 21.0 | 0.0066 | 0 | " | " | 56 | 1885 | 30 | |
| 704 | 0.3 | 1 | 2.3 | 2.3 | " | " | 27 | 4.0 | 0 | 160 | 13 | 20.9 | 0.0029 | 0 | " | " | 56 | 1925 | 65 | |
| 705 | 0.3 | 1 | 2.3 | 2.3 | " | " | 0 | 4.5 | 3 | 170 | 12 | 22.5 | 0.0029 | 0 | " | " | 56 | 1980 | 75 | |
| 710 | 0.3 | 1 | 2.3 | 2.3 | " | " | 0 | 4.0 | 4 | 240 | 15 | 21.6 | 0.0029 | 0 | " | " | 56 | 1870 | 55 | |
| 717 | 0.3 | 10 | 2.3 | 4 | " | Fe, round | 0 | 3.0 | 4 | 370 | 15 | 38.5 | 0.0066 | 0 | " | " | 56 | 1975 | 8 | General Electric |
| 719 | 0.3 | 15 | 2.3 | 4 | " | " | 0 | 3.5 | 4 | 410 | 33 | 14.1 | 0.0066 | 0 | " | " | 56 | 1980 | 5 | " |
| | | 15 | | 4 | | | 0 | 3.7 | 4 | 370 | 35 | 7.1 | 0.0029 | 0 | " | " | 56 | 2000 | 10 | |
| | | 15 | | 4 | | | | | 4 | 420 | 13 | 36.7 | 0.0029 | | | | 56 | 1990 | 20 | |
| 723 | 0.3 | 10 | 2.3 | 2.3 | " | Brass, flat | 0 | 5.0 | 4 | 240 | 21 | 18.6 | 0.0066 | 0 | " | " | 15 | 1945 | 18 | Lakon 15000 |
| 725 | 0.3 | 10 | 2.3 | 2.3 | " | Fe, round | 0 | 2.0 | 4 | 300 | 38 | 10.5 | 0.0066 | 0 | " | " | 15 | 2045 | 10 | " |
| 736 | 0.3 | 15 | 2.3 | 4 | " | " | 0 | 2.5 | 4 | 370 | 88 | 7.1 | 0.0029 | 0 | " | " | 15 | 2075 | 20 | " |
| 727 | 0.2 | 15 | 2.3 | 4 | " | " | 0 | 2.5 | 4 | 420 | 64 | 10.6 | 0.0029 | 0 | " | " | 15 | 2005 | 11 | |
| 767 | 1.0 | 6 | 2.3 | 4 | " | " | 0 | 4.5 | 4 | 400 | 45 | 17.8 | 0.0066 | 0 | " | " | 15 | 2075 | 20 | General Electric |
| 772 | 1.0 | 6 | 2.3 | 4 | " | " | 0 | 4.6 | 4 | 430 | 51 | 15.8 | 0.0066 | 0 | " | " | 15 | 1990 | 21 | " |
| 769 | 0.6 | 6 | 2.3 | 4 | " | " | 0 | 3.8 | 4 | 400 | 42 | 18.8 | 0.0066 | 0 | " | " | 15 | 1790 | 6 | " |
| 770 | 0.6 | 6 | 2.3 | 4 | " | " | 0 | 4.5 | 4 | 400 | 53 | 14.3 | 0.0066 | 0 | " | " | 15 | 1880 | 6.5 | " |
| 768 | 0.3 | 6 | 2.3 | 4 | " | " | 0 | | 4 | 330 | 44 | 19.3 | 0.0066 | 0 | " | " | 15 | | 5.5 | " |
| 771 | 0.3 | 6 | 2.3 | 4 | " | " | 0 | | 4 | 340 | 43 | 17.5 | 0.0066 | 0 | " | " | 15 | | | " |
| 694‡ | 0.1 | 3 | 2.3 | 4 | " | " | 0 | 4.0 | 2 | 500 | 33 | 24.0 | 0.0066 | 0 | " | 2% NaCl | 56 | 1805 | 40 | General Electric |
| 695‡ | 0.1 | 3 | 2.3 | 4 | " | " | 0 | 4.0 | 2 | 280 | 14 | 26.0 | 0.0066 | 0 | " | Tap water | 56 | 1880 | 4 | |

\* Over and above resistance of field coils of alternator and primary winding of transformer respectively.

† Potential difference at terminals of transformer.

‡ Slit of spectroscope 0.050 mm.; 0.025 in all other cases.

There sometimes appear diffuse emission lines with rather prominent maxima of intensity; these may be regarded as combinations of types (1) and (2), or of types (1) and (3). Such lines, however, are not very well marked, nor of frequent occurrence.

B. *Absorption phenomena produced by changing the constants of the circuit.*—In passing from the bright-line to the dark-line condition, the various lines of the spectrum do not all act in the same way. In general, when an emission line appears on successive plates, it is either (1) progressively enhanced to a maximum, and then progressively shattered and weakened, or (2) the line is simply progressively shattered and weakened without noticeable enhancement. If reversal occur before shattering, the resultant line will be of types (5), (6), or (7). Such a line is at first characterized by weak absorption and strong emission components. With decreasing self-induction in the discharge circuit of the condenser the absorption line becomes much stronger, and the emission line fades away. The brightening of an emission line is usually most prominent on the plate just preceding the one on which the line shows a reversal.

When, on the other hand, a bright line is shattered to complete obliteration without enhancement, there ensues a balancing of emission and absorption, and later the line appears as an absorption line of type (4).

Certain lines—for example, λλ 3606.85, 3677.71, 3738.40, 3765.70, 3797.64, 3827.98, 3841.21, 3893.50, and 3898.05—are notably enhanced (relatively to other lines) in the spectrum of the spark in water, when considerable self-induction is used in the discharge circuit. There are undoubtedly a number of other lines thus enhanced, but these are among the most prominent.

C. *Shifts of the lines produced by changing the constants of the circuit.*—For various reasons, chief among which is the long exposure required with the concave grating when the spark is faint, many of the experiments undertaken in the qualitative investigation were not repeated with the high-dispersion spectroscope. Thus nothing further was done with regard to the water-pressure effect, (paragraph 14, p. 40), phenomena obtained with two or more water- or air-gaps in series (paragraphs 3 and 4, p. 38), the effect of change in the diameter of the air-gap terminals (paragraph 6, p. 39), and change in the temperature of the liquid (paragraph 8, p. 39).

There remain the cases presented in paragraphs 1, 2, 5, 7, 9, 10, 11, 12, and 13. In nearly every instance the results obtained with the low dispersion apparatus were confirmed. When this was not the case, the reasons for the difference in the results are evident. The conditions under which the different plates were taken are given in Table VII, and the specific results of each set in Tables VIII–XII inclusive.

(1) *Change in diameter of water-gap terminals.*—The shifts of the lines on Plates 604, 697, 603, and 605, taken with water-gap terminals of 1.0 and 1.6, 2.3, and 4.0 mm. in diameter, respectively, are shown in the following table (VIII). For many of the lines there seems to be a distinct and progressive change toward greater absorption and greater shift as the diameter of the terminals increases.

*Change in length of water-gap.*—The shifts of the lines as measured on Plates 767, 772; 769, 770; 768, 771 (three sets of duplicate plates), are given in Table IX. No certain progression is shown in the case of absorption lines, but there seems to be a gradual shift toward the red with increasing water-gap in the case of a few emission lines.

*Change in length of air-gap.*—Shifts of the lines on Plates 702 and 685 are given in Table IX. There seem to be many cases of genuine shifts toward the red with increasing air-gap.

*Change of capacity.*—The shifts of the lines as shown on Plates 712, 704; 702; and 672, are given in Table VIII. Within the range studied the changes are small and irregular and of no certain meaning. Plates 704 and 712 are unique. With conditions similar to those under which these were taken—i. e., small capacity (0.003 microfarad), small air-gap (1 mm.), moderate water-gap (0.3 mm.)—we have usually obtained spectra which contained numerous lines of types (8), (9), and (10). Lines

## TABLE VIII

EFFECTS PRODUCED BY CHANGE IN DIAMETER OF WATER-GAP TERMINALS AND BY CHANGE OF CAPACITY

| | | Change in Diameter of Terminals | | | | Change of Capacity | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. of Plate | | 604 | 697 | 603 | 605 | 704 | 712 | 702 | 672 |
| Diameter of Terminals in mm. Capacity in Microfarads | | 1 | 1.6 | 2.3 | 4 | 0.003 | | 0.007 | 0.020 |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters: positive unless otherwise stated. Type of line in *italics*. Absorption lines indicated by $a$; emission by $e$. | | | | | | | |
| 3558.68 | 6 | 4 −0.03 a | 4 0.00 a | 4 −0.01 a | 4 0.05 a | (Faint a) | (Faint a) | 4 −0.01 a | 4 0.01 a |
| 65.54 | 8 | 5 − .02 a | 4 .01 a | 4 .01 a | 4 .05 a | 8 ——— | 8 0.02 e / .02 a | 4 − .01 a | 4 − .02 a |
| 87.10 | 5 | 4 − .01 a | 4 .02 a | 4 .05 a | 4 − .01 a | 4 0.00 a | (Faint a) | 4 − .03 a | 4 − .01 a |
| 3606.85 | 6 | 8 .34 e | .......... | 7 − .09 a | .......... | 3 .17 e | 3 .17 e | 2 .17 e | 7 .00 a |
| 48.00 | 9 | 5 .01 a | 5 .04 a | 4 .04 a | 4 .06 a | 8 ——— e / .04 a | 8 .04 e / .02 a | 4 − .05 a | .32 e / 4 .00 e |
| 51.60 | 4 | 2 .10 e | *J c* | | | | | | |
| 80.06 | 5 | 4 − .01 a | 4 .02 a | 4 .02 a | 4 .00 a | 4 .03 a | 4 .02 a | 4 − .01 a | 4 .03 a |
| 87.55 | 6 | 7 − .01 a / .34 e | 7 .01 a / .......... | 4 .01 a / — | 4 .02 a / .......... | (Faint a) | (Faint a) | 7 .00 a / .33 e | 4 .00 a |
| 3709.40 | 6 | 6 − .02 a / .38 e | 6 .04 a / .......... | 6 .04 a | 4 .04 a / .......... | 7 ——— | 7 | 7 .01 a / .32 e | 4 − .01 a |
| 22.73 | 6 | 4 − .03 a | 4 .01 a | 4 .07 a | 4 .09 a | 4 .05 a | 4 .07 a | 4 − .01 a | 4 .00 a |
| 27.78 | .. | 6 − .05 a | 6 .00 a | 4 .03 a | 4 .02 a | (Faint a) | (Faint a) | 5 .00 a | 4 .01 a |
| 33.46 | 6 | 4 − .03 a | 4 .02 a | 4 .02 a | 4 .04 a | 4 .03 a | 4 .01 a | 4 − .02 a | 4 .02 a |
| 43.51 | 7 | 7 − .04 a / .29 e | 7 − .01 a / .35 e | 4 .01 a / .......... | 4 .03 a / .......... | 7 ——— | 7 − .03 a / .32 e | 7 .02 a / .31 e | 7 .00 a |
| 58.39 | 8 | 5 .00 a | 4 .04 a | 4 .05 a | 4 .03 a | 8 − .02 e / .04 a | 8 − .01 e / .05 a | 6 .00 a | 4 .00 a |
| 63.91 | 7 | 5 .02 a | .......... a | 4 .02 a | 4 .05 a | 8 ——— | 8 − .01 e / − .00 a | 4 − .02 a | 4 .01 a |
| 65.70 | 5 | 2 .18 e | 2 .19 e | 3 .18 e | 3 .29 e | 3 .13 e | 3 .15 e | 2 .14 e | 3 .15 e |
| 67.32 | 7 | 6 − .02 a | 6 .04 a | 6 .04 a | 4 .03 a | 6 ——— | 6 .06 a | 4 − .03 a | 4 .00 a |
| 95.15 | 6 | 5 − .06 a | 5 .04 a | 5 .02 a | 4 .06 a | 5 ——— | 5 .......... | 5 − .04 a | 4 .00 a |
| 99.70 | 7 | .......... | 6 − .01 a | 6 .09 a | 4 .00 a | (Lacking) | 7 Very faint | 7 .......... | 4 − .02 a |
| 3805.48 | 5 | 2 .08 e | 2 .......... e | 2 .15 e | 2 .15 e | | | | |
| 15.99 | 9 | 6 .00 a | 6 .03 a | 6 .04 a | 4 .05 a | 8 .......... | 8 − .01 e / − .03 a | 6 .01 a | 4 .02 a |
| 24.58 | 7 | 4 .00 a | 4 .04 a | 4 .05 a | 4 .06 a | 4 .07 a | 4 .08 a | 4 .03 a | 4 .03 a |
| 27.98 | 9 | 5 − .01 a | 5 .05 a | 4 .05 a | 4 .09 a | 8 ——— | 8 .......... | 7 .03 a / .48 e | 6 .04 a |
| 34.38 | 8 | 5 − .02 a | 5 .04 a | 4 .03 a | 4 .01 a | 8 ——— | 8 .03 e / .07 a | 5 .00 a | 4 .00 a |
| 56.51 | 8 | 5 − .01 a | 4 .03 a | 4 .03 a | 4 .04 a | 4 .07 a | 4 .......... | 4 .01 a | 4 .03 a |

of this type require further study, as the method employed in measuring the position of the absorption part of the combination was unsatisfactory, owing to the fine thread required for other work with the measuring machine.

*Change of self-induction in the discharge circuit.*—The shifts obtained for measures of Plates 659, 651, 650, 658, 666, and 665 are given in Table X. Change of self-induction is much more satisfactory than any other means for controlling the absorption phenomena and the shifts of the lines. It also has the advantage of sharpening the lines, which results in increased accuracy of measurement. In the region under investigation the change from a bright line spectrum to one consisting almost wholly of absorption lines is nearly complete, though in the less refrangible region comparatively few lines are reversed, even when all self-induction is removed from the secondary circuit. (See Plate XIX.)

Wilsing's photograph of the iron spectrum in water, as far as can be judged from the description of the lines in his table (see Table I, p. 32), lies between our Plates 666 and 665 of the self-induction series. But according to line λ3765.70 (the central line of the triplet) the absorption is greater on his plate than on our No. 665 (for which no self-induction was used). On his plate

## TABLE IX

### Effects Produced by Change in Length of Water Gap and Air-Gap

| No. of Plate | | Change of Water-Gap | | | | | | | | | Change of Air-Gap | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 767 and 772 | | | 769 and 770 | | | 768 and 771 | | | 702 | | | 685 | | |
| Water-Gap 1.0 to 0.3 mm. Air-Gap 1 to 15 mm. | | 1.0 | | | 0.6 | | | 0.3 | | | 1 | | | 15 | | |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters: positive unless otherwise stated. Type of line in *italics*. Absorption lines indicated by *a*; emission line by *e*. | | | | | | | | | | | | | |
| 3558.68 | 6 | | ............ | | 7 | 0.02 | *a* | 4 | 0.02 | *a* | 4 | −0.01 | *a* | 4 | 0.04 | *a* |
| | | | | | | —— | *e* | | | | | | | | | |
| 65.54 | 8 | 5 | −0.01 | *a* | 6 | −.01 | *a* | 4 | −.02 | *a* | 4 | −.01 | *a* | 4 | .02 | *a* |
| 87.10 | 5 | 6 | .04 | *a* | 6 | .00 | *a* | 4 | .00 | *a* | | ............ | | | ............ | |
| 3606.85 | 6 | 2 | .17 | *e* | 2 | .29 | *e* | 7 | −.05 | *a* | 2 | .17 | *e* | 7 | .02 | *a* |
| | | | | | | | | | .27 | *e* | | | | | .32 | *e* |
| 40.53 | 5 | 2 | .07 | *e* | 2 | .11 | *e* | 2 | .14 | *e* | | ............ | | | ............ | |
| 48.00 | 9 | 5 | .01 | *a* | 5 | .02 | *a* | 4 | .00 | *a* | 4 | −.05 | *a* | 4 | .03 | *a* |
| 51.60 | 4 | 2 | .08 | *e* | 2 | .12 | *e* | 2 | .13 | *e* | | ............ | | | ............ | |
| 80.06 | 5 | | ............ | | 4 | .03 | *a* | 4 | .02 | *a* | 4 | −.01 | *a* | 4 | .02 | *a* |
| 87.55 | 6 | | ............ | | 6 | .01 | *a* | 6 | .00 | *a* | 7 | .00 | *a* | 4 | .01 | *a* |
| | | | | | | | | | | | | .33 | *e* | | | |
| 3709.40 | 6 | | ............ | | 6 | .02 | *a* | 6 | .02 | *a* | 7 | .01 | *a* | 4 | .03 | *a* |
| | | | | | | | | | | | | .32 | *e* | | | |
| 22.73 | 6 | 4 | .01 | *a* | 5 | .02 | *a* | 4 | .02 | *a* | 4 | −.01 | *a* | 4 | .03 | *a* |
| 27.78 | ...... | | ............ | | 6 | .02 | *a* | 6 | .03 | *a* | 5 | .00 | *a* | 4 | .03 | *a* |
| 33.46 | 6 | 4 | .03 | *a* | 4 | .02 | *a* | 4 | .03 | *a* | 4 | −.02 | *a* | 4 | .01 | *a* |
| 43.51 | 7 | | ............ | | 6 | −.01 | *a* | 6 | .03 | *a* | 7 | .02 | *a* | 7 | .02 | *a* |
| | | | | | | | | | | | | .31 | *e* | | —— | *e* |
| 58.39 | 8 | 5 | .03 | *a* | 5 | .02 | *a* | 4 | .04 | *a* | 6 | .00 | *a* | 4 | .05 | *a* |
| 63.91 | 7 | 5 | .02 | *a* | 5 | .04 | *a* | 4 | .05 | *a* | 4 | −.02 | *a* | 4 | .02 | *a* |
| 65.70 | 5 | 2 | .10 | *e* | 2 | .13 | *e* | 2 | .18 | *e* | 2 | .14 | *e* | 7 | .02 | *a* |
| | | | | | | | | | | | | | | | .27 | *e* |
| 67.32 | 7 | 6 | .01 | *a* | 6 | .02 | *a.* | 6 | .03 | *a* | 4 | −.03 | *a* | 4 | .04 | *a* |
| 95.15 | 6 | | ............ | | | ............ | | | ............ | | 5 | −.04 | *a* | 5 | −.02 | *a* |
| 99.70 | 7 | | ............ | | | ............ | | | ............ | | | ............ | | | ............ | |
| 3805.48 | 5 | 2 | .09 | *e* | 2 | .10 | *e* | 2 | .11 | *e* | | ............ | | | ............ | |
| 15.99 | 9 | 6 | .04 | *a* | 6 | .04 | *a* | 6 | .05 | *a* | 6 | .01 | *a* | 6 | .01 | *a* |
| 24.58 | 7 | 4 | .07 | *a* | 4 | .05 | *a* | 4 | .06 | *a* | 4 | .03 | *a* | 4 | .05 | *a* |
| 27.98 | 9 | 6 | .09 | *a* | 6 | .05 | *a* | 6 | .04 | *a* | 7 | .03 | *a* | 4 | .07 | *a* |
| | | | | | | | | | | | | .48 | *e* | | | |
| 34.38 | 8 | 5 | .02 | *a* | 5 | .03 | *a* | 5 | .03 | *a* | 5 | .00 | *a* | 4 | .02 | *a* |
| 56.51 | 8 | | ............ | | | ............ | | | ............ | | 4 | .01 | *a* | 4 | .05 | *a* |

λ 3765.70 is of type 7; while on our plate this line is of type 2. From this and other facts, to be mentioned later, it may perhaps be inferred that all lines do not move toward absorption in the same manner under different conditions; i. e., given two plates, taken under widely different conditions, showing *in general* the same absorption, upon these plates there may be some cases in which the same line is at a different stage of absorption.

*Change of ohmic resistance in the discharge circuit.*—Measures of the shifts of the lines of Plate 716, which are given in Table XI, show that the displacements are in general slightly greater than those of Plate 666 of the self-induction series. The absorption, however, appears to be somewhat less marked, and the lines are not as sharp as those of the plate taken with self-induction.

*Change of resistance in field circuit of alternator:* Plates 723 and 725; also 726 and 727 (no measurements made).—Plate 725 (resonance) shows unmistakably greater absorption than 723. Plates 726 and 727 (as well as another set made under slightly different conditions) show no difference. This might perhaps be due to the small difference in resistance (40 and 27 ohms) and the extended exposures (20 and 11 minutes), during which resistance changes are introduced owing to change in temperature of the wires.

## TABLE X

### Effect Produced by Change of Self-Induction

| No. of Plate | | 659 | | | 651 | | | 650 | | | 658 | | | 666 | | | 665 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Self-Induction in No. of Turns of Coil** | | 143 | | | 104 | | | 54 | | | 27 | | | 14 | | | 0 | | |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters: positive unless otherwise stated. Type of line in *italics*. Absorption lines indicated by *a*; emission, by *e*. | | | | | | | | | | | | | | | | |
| 3558.68 | 6 | 2 | 0.04 | e | 2 | 0.03 | e | 2 | 0.07 | e | 7 | −0.06 / .27 | a / e | 7 | 0.04 / .... | a / e | 4 | 0.03 | a |
| 65.54 | 8 | 2 | .06 | e | 3 | .07 | e | 7 | −.08 / .25 | a / e | 6 | −.00 | | 4 | −.00 | a | 4 | .00 | a |
| 87.10 | 5 | 2 | .02 | e | 2 | .06 | e | Faint | | e | 7 | −.09 / .... | a / e | 4 | −.01 | a | 4 | −.01 | a |
| 3606.85 | 6 | 2 | .01 | e | 2 | .02 | e | 2 | .04 | e | 2 | .08 | e | 2 | .14 | e | 7 | −.01 / .28 | a / e |
| 40.53 | 5 | 2 | .02 | e | .... | | | 2 | .03 | e | .... | | | 2 | .08 | e | .... | | |
| 48.00 | 9 | 3 | .08 | e | 2 | .07 | e | 6 | −.05 / .22 | a / e | 6 | −.03 | a | 4 | −.01 | a | 4 | .02 | a |
| 80.06 | 5 | Faint | | e | Lacking | | | Faint | | a | 4 | −.00 | a | 4 | .01 | a | 4 | .00 | a |
| 87.55 | 6 | 2 | .09 | e | 2 | .08 | e | 2 | .08 | e | 7 | −.02 / .26 | a / e | 7 | −.02 / .27 | a / e | 4 | −.01 | a |
| 3709.40 | 6 | 3 | .07 | e | 3 | .09 | e | 2 | .09 | e | 7 | .02 / .28 | a / e | 7 | .02 / .33 | a / e | 4 | .03 | a |
| 22.73 | 6 | Faint | | | Faint | | | Faint | | | 4 | ±.00 | a | 4 | .02 | a | 4 | .01 | a |
| 27.78 | .. | 2 | .08 | e | 2 | .09 | e | 2 | .13 | e | 6 | −.03 | a | 6 | −.03 | a | 4 | .01 | a |
| 33.46 | 6 | Faint | | e | Lacking | | | 4 | .02 | a | 4 | .03 | a | 4 | .02 | a | 4 | −.01 | a |
| 43.51 | 7 | 2 | .06 | e | 2 | .06 | e | 2 | .09 | e | 7 | −.06 / .25 | a / e | 7 | −.03 / .28 | a / e | 7 | −.01 / .30 | a / e |
| 58.39 | 8 | 3 | .07 | e | 3 | .09 | e | 7 | −.05 / .24 | a / e | 6 | .02 | a | 6 | .02 | a | 4 | .02 | a |
| 63.91 | 7 | 3 | .05 | e | 2 | .06 | e | 2 | .21 | e | 6 | .01 | a | 4 | .00 | a | 4 | .01 | a |
| 65.70 | 5 | 2 | .02 | e | 2 | .03 | e | 2 | .01 | e | -2 | .09 | e | 2 | .10 | e | 3 | .21 | e |
| 67.32 | 7 | 2 | .03 | e | 2 | .03 | e | 2 | .06 | e | 7 | .01 / .32 | a / e | 7 | .01 / .31 | a / e | 4 | .02 | a |
| 95.15 | 6 | 2 | .04 | e | 2 | .08 | e | 2 | .10 | e | 2 | .28 | e | 6 | −.02 | a | 6 | −.02 | a |
| 99.70 | 7 | 2 | .03 | e | 2 | .03 | e | 2 | .04 | e | Faint | | a | 7 | .01 / .22 | a / e | 4 | .03 | a |
| 3815.99 | 9 | 3 | .05 | e | 3 | .07 | e | 3 | .12 | e | 6 | −.00 | a | 6 | .01 | a | 6 | .03 | a |
| 24.58 | 7 | Faint | | | Faint | | | 4 | .03 | a | 4 | .04 | a | 4 | .04 | a | 4 | .03 | a |
| 27.98 | 9 | 3 | .02 | e | 3 | .05 | e | 2 | .09 | e | 7 | −.01 / .35 | a / e | 6 | −.00 | a | 4 | .02 | a |
| 34.38 | 8 | 2 | .03 | e | 2 | .07 | e | 2 | .14 | e | 6 | −.01 | a | 6 | .01 | a | 4 | .02 | a |
| 56.51 | 8 | Faint | | e | Faint | | e | Faint | | e | 4 | .01 | a | 4 | .02 | a | 4 | .02 | a |
| 4045.98 | 10 | 2 | .01 | e | 2 | .02 | e | 2 | .09 | e | 5 | .02 | a | 5 | .02 | a | 4 | .06 | a |
| 63.75 | 10 | 2 | .03 | e | 2 | .02 | e | 2 | .04 | e | 6 | .06 | a | 6 | .02 | a | 4 | .02 | a |
| 71.92 | 10 | 2 | .02 | e | 2 | .03 | e | 2 | .03 | e | 6 | −.03 | a | 6 | .03 | a | 4 | .05 | a |
| 4118.72 | 5 | 2 | .02 | e | .... | | | .... | | | 2 | .03 | e | 2 | .03 | e | .... | | |
| 99.27 | 8 | 2 | .02 | e | 2 | .04 | e | 2 | .00 | e | 2 | .06 | e | 2 | .06 | e | 2 | .11 | e |
| 4294.32 | 6 | 2 | .02 | e | 2 | .02 | e | .... | | | 2 | .02 | e | 2 | .06 | e | Faint | | e |
| 4308.06 | 10 | 2 | .02 | e | 3 | .05 | e | 2 | .06 | e | 6 | −.05 | a | 6 | −.01 | a | 6 | .02 | a |
| 25.94 | 10 | 3 | .02 | e | 3 | .04 | e | 2 | .03 | e | 6 | −.01 | a | 6 | −.03 | a | 6 | .01 | a |
| 83.71 | 10 | 3 | .05 | e | 3 | .05 | e | 2 | .15 | e | 6 | −.01 | a | 6 | −.01 | a | 6 | .02 | a |
| 4404.94 | 10 | 2 | .03 | e | 2 | .05 | e | 2 | .04 | e | 6 | −.11 | a | 6 | −.04 | a | 6 | .02 | a |
| 15.29 | 8 | 2 | .05 | e | 2 | .02 | e | 2 | .02 | e | 2 | .12 | e | 2 | .12 | e | Trace of 7 | | |

*Change of resistance in primary circuit of transformer:* Plates 712, 719 (no measurements made).—No difference is apparent in either set. Here again the small difference between 0 and 3, and 0 and 4, ohms in the transformer circuit might perhaps explain the failure to obtain a difference.

*Change of transformer:* Plates 704, 705, 710 (no measurements made). — The absorption shown upon the plate obtained with the Lakon transformer with the 30,000 volt connections is greater than that obtained with the 15,000 volt combination; and the Lakon 15,000 and Lewis Institute transformer plates are identical. The difference noted above consists mainly, but not wholly,

### TABLE XI
#### EFFECT OF OHMIC RESISTANCE COMPARED WITH THAT OF SELF-INDUCTION

| NO. OF PLATE | | 716 | | | 666 | | |
|---|---|---|---|---|---|---|---|
| Ohmic Resistance and Self-Induction Conditions | | 18.5 meters No. 23 Copper Wire | | | 14 Turns of Self-Induction Coil | | |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters: positive unless otherwise stated. Type of line in *italics*. Absorption lines indicated by *a*; emission by *e*. | | | | | |
| 3558.68 | 6 | *7* | **0.01** | *a* | *7* | **− 0.04** | *a* |
|  |  |  | **.31** | *e* |  | ...... | *e* |
| 65.54 | 8 | *5* | **.01** | *a* | *4* | **.00** | *a* |
| 87.10 | 5 | *5* | **.01** | *a* | *4* | **− .01** | *a* |
| 3606.85 | 6 | *2* | **.15** | *e* | *2* | **.14** | *e* |
| 48.00 | 9 | *6* | **.00** | *a* | *4* | **−.01** | *a* |
| 80.06 | 5 | *4* | **.01** | *a* | *4* | **.01** | *a* |
| 87.55 | 6 | *6* | **− .01** | *a* | *7* | **− .02** | *a* |
|  |  |  |  |  |  | **.27** | *e* |
| 3709.40 | 6 | *7* | **.00** | *a* | *7* | **.02** | *a* |
|  |  |  | **.34** | *e* |  | **.33** | *e* |
| 22.73 | 6 | *4* | **.01** | *a* | *4* | **·02** | *a* |
| 27.78 |  | *6* | **.01** | *a* | *6* | **.03** | *a* |
| 33.46 | 6 | *4* | **− .01** | *a* | *4* | **.02** | *a* |
| 43.51 | 7 | *7* | **− .02** | *a* | *7* | **− .03** | *a* |
|  |  |  | **.28** | *e* |  | **.28** | *e* |
| 58.39 | 8 | *4* | **.02** | *a* | *6* | **.02** | *a* |
| 63.91 | 7 | *6* | **.01** | *a* | *4* | **.00** | *a* |
| 65.70 | 5 | *2* | **.13** | *e* | *2* | **.10** | *e* |
| 67.32 | 7 | *6* | **.00** | *a* | *7* | **.01** | *a* |
|  |  |  |  |  |  | **.31** | *e* |
| 99.70 | 7 | *7* | **− .01** | *a* | *7* | **.01** | *a* |
|  |  |  | **.31** | *e* |  | **.22** | *e* |
| 3815.99 | 9 | *6* | **.00** | *a* | *6* | **.01** | *a* |
| 24.58 | 7 | *4* | **.08** | *a* | *4* | **.04** | *a* |
| 27.98 | 9 | *6* | **.05** | *a* | *6* | **.00** | *a* |
| 34.38 | 8 | *5* | **.00** | *a* | *6* | **.01** | *a* |
| 56.51 | 8 | *4* | **.05** | *a* | *4* | **.02** | *a* |

in changes from types of lines Nos. 8, 9, and 10 (strong, sharp, bright lines in the center of absorption lines), with the Lewis Institute and Lakon 15,000 instruments, to types in which the bright line is weak or, like types 5, 6, and 7, wholly lacking — this in the case of the Lakon with 30,000 volt connections.

From data at hand it cannot be stated whether one transformer will always give more or less absorption than another. All that can be said is that regular differences occur, and that the plates showing such differences can usually be repeated. It may be seen in Table VII that the power in watts was about the same for plates 704 and 705, but considerably greater for 710, the plate which shows the greatest absorption.

From general considerations it might seem that the total power consumed in the gap would determine the amount of the absorption displayed by the spectrum. By referring to Table VII, and

by studying the character of the spectra as denoted by shift and absorption in Tables VIII–XI, it may be seen that the greatest absorption usually accompanies the highest readings of the watt meter.

But we note that this is not true in the plates of the self-induction series. This points to the fact that the suddenness of the discharge is an important factor in determining the absorption. Self-induction lengthens the time of the discharge, and the result is an emission spectrum.

At this point we may also give the results obtained with the *2 per cent. salt solution* when high dispersion was employed. Plates 694 and 695 (Table XII) were taken under identically the same conditions, except that the liquid used in the latter case was tap water, while for Plate 694 a 2 per cent. sodium chloride solution in tap water was used. Both plates were measured twice with considerable care. All but four of the lines measured show displacements toward the red in the salt solution as compared with their positions in the tap water. Moreover, $\lambda\,3827.98$, which is one of the lines not displaced, acts abnormally in Plates 767–772 (length of water-gap series), where it does not follow the general rule, but shows greater shift at less absorption.

TABLE XII

Tap Water and 2 Per Cent. Salt Solution

Comparison of duplicate measurements of Plates 694 and 695; $\Delta\lambda_1$ and $\Delta\lambda_2$, the means of the same; and $\Delta\lambda_1-\Delta\lambda_2$, or the excess displacement in the salt solution over that in the tap water.

| No. of Plate | | 694 | | | | 695 | | | | $\Delta\lambda_1-\Delta\lambda_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Liquid Used | | 2 per cent. *Na Cl* Solution | | | | Tap Water | | | | |
| | | Displacements | | Mean $\Delta\lambda_1$ | Types of Lines | Displacements | | Mean $\Delta\lambda_2$ | Types of Lines | |
| Wave-Lengths | Intensities | Measurement | | | | Measurement | | | | |
| | | No. 1 | No 2 | | | No. 1 | No. 2 | | | |
| 3687.55 | 6 | 0.01 | 0.01 | 0.010 | 4  a* | 0.00 | 0.00 | 0.000 | 4  a* | 0.010 |
| 3708.06 | 5 | .01 | .00 | .005 | 4  a | − .03 | − .04 | − .035 | 7  a<br>..... e | .040 |
| 58.39 | 8 | .01 | .00 | .005 | 5  a | .00 | .01 | .005 | 4  a | .000 |
| 63.91 | 7 | .03 | .03 | .030 | 4  a | .00 | .00 | .000 | 4  a | .030 |
| 65.70 | 5 | .27 | .27 | .270 | 2  e | .17 | .19 | .180 | 2  e | .090 |
| 67.32 | 7 | .03 | .05 | .040 | 4  a | .01 | .02 | .015 | 4  a | .025 |
| 88.02 | 5 | − .01 | .00 | − .005 | 4  a | .01 | − .01 | .000 | 4  a | −.005 |
| 99.70 | 7 | .04 | .01 | .025 | 4  a | .03 | .03 | .030 | 4  a | −.005 |
| 3805.48 | 5 | .05 | .23 | .240 | 3  e | .12 | .13 | .125 | 3  e | .115 |
| 13.12 | 5 | .01 | .01 | .010 | 4  a | .00 | − .02 | − .010 | 4  a | .020 |
| 27.98 | 9 | .03 | .03 | .030 | 4  a | .03 | .04 | .035 | 4  a | −.005 |
| 34.38 | 8 | .03 | .03 | .030 | 4  a | − .02 | − .01 | − .015 | 4  a | .045 |
| 4045.98 | 10 | .04 | .03 | .035 | 4  a | .01 | .02 | .015 | 4  a | .020 |
| 63.75 | 10 | .07 | .08 | .075 | 4  a | .01 | .00 | .005 | 4  a | .070 |
| 4308.06 | 10 | .03 | .04 | .035 | 4  a | − .02 | .00 | − .010 | 6  a | .045 |
| 25.94 | 10 | .02 | .01 | .015 | 4  a | − .02 | − .02 | − .020 | 6  a | .035 |
| 83.71 | 10 | − .01 | .00 | − .005 | 6  a | − .03 | − .02 | − .025 | 6  a | .020 |
| 4404.94 | 10 | .02 | .03 | .025 | 6  a | − .07 | − .06 | − .065 | 6  a | .090 |

*a signifies absorption line; e emission line.

The spectrum of a *rotating arc* (direct current, 110 volts) between iron electrodes in water showed a bright line spectrum, marked by a few lines not present in air and therefore probably due to the surrounding liquid. No absorption lines were shown. From a plate taken at low dispersion, in the qualitative part of this investigation, it was found that the spectrum of the Wehnelt break (iron and lead in potassium hydroxide) similarly contains no absorption lines in the region examined.

The question naturally arises: Does a definite displacement correspond to a definite degree of absorption for any given liquid, no matter how different may be the electrical conditions under which the two plates giving the same absorption are obtained? Plate 716 (in which resistance was inserted

in the discharge circuit of the condenser) shows slightly less absorption than Plate 666. It falls between Plates 666 and 658. In amount of shift six lines lie between 658 and 666, and sixteen lines lie above 666. Apparently the facts are not such as would justify any general conclusion, for the number of lines studied is too small. Reference may be made, however, to many marked differences between the shifts observed by Wilsing and by ourselves, on plates showing nearly the same degree of absorption (p. 32).

### DISCUSSION OF RESULTS OBTAINED WITH THE SPARK IN LIQUIDS

When a high-potential discharge takes place between metallic poles in liquids, two causes unite to produce a very rapid increase of pressure in the immediate neighborhood of the poles: (1) the sudden production of a very high temperature, and (2) the sudden production of metallic vapor shot out from both poles. At each discharge a pressure wave moves out from the poles, the maximum pressure produced and the pressure gradient depending upon a variety of circumstances, chief among which are the nature of the discharge, the physical and chemical properties of the liquid and the character of the metal of which the poles are composed. Let us consider briefly the bearing of these various factors upon the resultant effect.

*The pressure as affected by the character of the discharge.*—From the investigations of Schuster and Hemsalech we know that the character of the discharge of the condenser is very different under different conditions in the circuit. When the resistance and self-induction of the circuit are very small, almost all the energy passes in the initial discharge. When water resistance is inserted in the circuit, it produces an intermittent discharge in which but little vapor is given off from the poles. The introduction of self-induction produces an oscillatory discharge, which is rendered comparatively slow by the opposing currents induced in the self-induction coil. Under these latter circumstances the initial discharge becomes more feeble, and the succeeding oscillations more marked and slower. The bearing of these results of Schuster and Hemsalech upon the pressure phenomena encountered in the present investigation is sufficiently obvious. As we have shown, the highest pressures are obtained when the resistance and self-induction of the discharge circuit are very small— i. e., under circumstances which tend to concentrate the energy in the first discharge. When water resistance is introduced, the spectroscopic phenomena entirely correspond with such a change in the spark as would involve loss of energy and less vaporization of the metallic poles. Self-induction in the circuit not only tends to reduce the energy of the discharge, but also makes it less sudden, on account of the distribution of the energy over the successive oscillations. We should therefore expect a very marked effect of self-induction upon the spectroscopic phenomena, and this is fully realized in practice.

The marked change in the spectrum produced by increasing the length of the spark in the liquid would seem to indicate that the energy of the discharge is greatly decreased in this way. After it had been noticed that the terminals wear away rapidly with a water-spark from 0.1 mm. to 0.3 mm. long, and slowly with a spark from 0.8 mm. to 1.0 mm. long, it was thought that the great difference in the amount of vapor produced under the two conditions might account for the observed differences in the spectrum. However, the experiments described on page 44 clearly prove that the effect is not confined to the spectrum of the spark under observation, but may be produced by changing the length of a second liquid spark in series with the first. It thus appears that the effect is probably due to a decrease in the energy of the discharge, which may be brought about by the insertion of a liquid resistance in any part of the discharge circuit.

The effect of changing the length of the air-gap is what might have been anticipated, as the potential of the discharge is thus increased, and this results (for any given capacity) in an increase in the quantity of electrical energy involved in each discharge. An increase in the diameter of the air-gap or water-gap terminals would also tend to increase the potential of the discharge, though in the latter case the effect of increased absorption is more probably due to a restriction of the volume

occupied by the vapor and a consequent increase in its density owing to the more extensive boundary walls of the larger terminals.

An increase of capacity would be expected to increase the energy of the discharge, and therefore to produce increased absorption, such as we have observed to occur.

The effect of self-induction and of ohmic resistance in the discharge circuit has already been mentioned. In both cases the results were what one would expect.

The effects produced by varying the field resistance of the alternator, the resistance in the primary circuit of the transformer, or of changing the transformer itself, probably arise from the influence of such changes upon the energy involved in each discharge and the degree of disruptiveness produced in the spark.

The three properties of liquids which seem to be most directly concerned are (1) the density, (2) the electrical conductivity, and (3) the tendency to unite chemically with the metal of the electrodes.

1. Other things being equal, the degree of absorption would presumably increase with the density of the liquid; but differences of conductivity, and of the chemical effects of different liquids, frequently mask effects caused by differences of density alone.

2. We should expect, with a liquid of considerable electrical conductivity, that the increased leakage between the terminals would tend to reduce the potential of the discharge, and therefore its energy. The experiments already described with liquids of different conductivities do not seem to conflict with this view. It is true that when the concentration of a salt solution is increased, thereby, in general, increasing its conductivity, the absorption phenomena become more marked. But it has been shown that this is probably due to increased chemical action between the liquid and the electrodes, which would tend to produce a greater volume of vapor, and thus to offset the loss arising from leakage between the terminals.

3. We were led by our spectroscopic experiments to the conclusion that the presence of a salt in the solution causes the metal of the terminals to vaporize more rapidly. This was before we had become acquainted with the work of Bredig and Haber, who reached the same conclusion, after studying the pulverization of the electrodes by an entirely different method, involving no spectroscopic observations.

## II. THE SPECTRUM OF THE HIGH POTENTIAL DISCHARGE BETWEEN METALLIC ELECTRODES IN GASES AT HIGH PRESSURES

In connection with the early part of this investigation, the blue region of the iron spectrum of the transformer spark in air was observed at pressures up to 20 atmospheres. The measured values of the shifts harmonized fairly well with those of Humphreys and Mohler, obtained with the arc at lower pressures. The metallic lines remained fairly sharp and were shifted toward the red by an amount which seemed to be directly proportional to the pressure (Plate XXII).

In his paper "On the Interpretation of the Typical Spectrum of the New Stars,"[20] Professor Wilsing concludes that the pressure resulting from the spark discharge in liquids amounts to several hundred atmospheres. As our own investigations led us to the belief that the pressure, at least in the case of our iron spark, was in reality much lower, we thought it desirable to extend our earlier work on spark spectra in air at high pressures to the more refrangible region studied in the case of liquids. As the apparatus previously used for such work proved inadequate, a new pressure tank was constructed in the Observatory instrument shop, and with this no difficulty was experienced in photographing the spectrum of the iron spark in gases at pressures ranging from 1 to 53 atmospheres.

This pressure tank was made of two cylindrical pieces of steel 11 cm. and 13 cm. long respectively, and 8.5 cm. in diameter. One of these was threaded, the other tapped, and both were bored

out so that the inclosed chamber was 16 cm. long and 5.5 cm. in diameter. The spark was produced between terminals screwed on rods, which were arranged as in the brass tank used in the investigation of the discharge in water, except that the ebonite insulators were conical and were set in cone-shaped receptacles to withstand high pressures. The light from the spark passed through a glass window, which had an aperture of 8 mm. and was 5 mm. thick. This also was cone-shaped to prevent its blowing out. Nut-heads were cut on each end of the cylinder, and special wrenches were made to screw and unscrew the two parts. A copper washer rendered the instrument air-tight. The receptacle was tapped for outlet, inlet, and pressure gauge. The compressed air and carbon dioxide were led in by a spiral tube from high-pressure tanks. When carbon dioxide was used, the window was taken off, and the gas allowed to escape freely for ten seconds before the tank was closed.

The accessory air-spark was always employed; without it the discharge was intermittent at best and often refused to pass at all. The secondary potential difference in certain cases ran as high as 19,000 volts in actual operation.

As stated above, the spectra photographed in the earlier work at high pressures did not extend into the ultra-violet. It had been shown that the reversals of the lines in the case of spark spectra in liquids appear first in the ultra-violet, and advance gradually toward the less refrangible region as the conditions for reversal become more favorable. A similar result was shown many years ago by Liveing and Dewar to obtain in the case of arc reversals. It is for this reason that the phenomena to be described were not encountered by us in our earlier work at lower pressures on the less refrangible region of the spectrum of the iron spark in air. Nevertheless, we were somewhat surprised to find, in our first test of the new apparatus, that at an air pressure of 14 atmospheres the reversal phenomena in the region $\lambda 3550$–$\lambda 4500$ closely resembled those we were accustomed to photograph in the case of the iron spark in water with but little self-induction in the discharge circuit. It was at once evident that a series of photographs made at different air pressures would resemble the series previously obtained with the spark in water by varying the self-induction. Photographs were therefore made at pressures ranging from 1 to 53 atmospheres, portions of which are reproduced in Plate XXI. In the temporary absence of compressed air at pressures greater than 14 atmospheres, liquid carbon dioxide was used to give higher pressures. It has since been found, moreover, that changes of self-induction in the discharge circuit of the condenser affect the reversal phenomena in the same sense as in the case of the spark in water, but over a smaller range.

An examination of Plate XXI will show that the phenomena closely resemble those described in the case of liquids (see p. 51). At an air pressure of 3.3 atmospheres the lines are for the most part bright, though a few cases of reversal appear. It will be noticed that a few of the lines have at this stage increased very markedly in relative intensity. Such lines, as the subsequent photographs show, pass through a maximum of intensity and afterward reverse. At a pressure of 7.3 atmospheres the bright lines are broader and more diffuse, and the absorption lines are becoming prominent. It is evident from inspection that many of the reversals are not symmetrical, the bright line being relatively displaced toward the red. At a pressure of 14 atmospheres the dark lines have become very conspicuous, and many of the bright lines have almost disappeared. Some evidences of a continuous spectrum begin to appear at this pressure. At 27.3 atmospheres (in carbon dioxide) the continuous spectrum is quite conspicuous. The absorption lines are strong, and the bright lines are much fainter than before. At 53.3 atmospheres (also in carbon dioxide) the bright lines have practically disappeared in this region and the dark lines remain, broad and diffuse, on a background of bright continuous spectrum. At this pressure most of those lines whose intensity is increased at moderate pressures are reversed, and the relative intensities of all the dark lines closely resemble those of the bright lines in the spectrum of the iron spark at atmospheric pressure. Even at the highest pressures few, if any, lines less refrangible than $\lambda 4415$ are reversed. In the region $\lambda 4800$–$\lambda 4900$ there are several strong lines unsymmetrically broadened in carbon dioxide at 53.3 atmospheres, and similarly

affected in water. It seems to be true that the order in which various lines reverse is not always precisely the same in gases as in liquids. For instance, line $A$ may be an absorption line in water when line $B$ is an emission line, while in air line $A$ may be bright when $B$ is dark. With the spark in air at pressures somewhat greater than one atmosphere the noticeable effect is generally an enhancement of the lines. The spark increases in brilliancy and becomes very disruptive; moreover, the air lines disappear at comparatively low pressures.

A preliminary study of the shifts of the bright and dark lines at these various pressures has brought out certain facts, which are of interest in connection with the results obtained by Humphreys and Mohler on the low potential discharge in air at high pressures, and our own results on the spectra of high potential discharges in liquids.

The following tables contain data concerning several plates and show the displacements of a few lines which may be regarded as fairly typical.

Table XIII gives the pressure and the constants of the electrical circuit which were used in the various cases.

### TABLE XIII

PHYSICAL AND ELECTRICAL CONDITIONS DURING EXPOSURES. IRON TERMINALS IN AIR AND CARBON DIOXIDE UNDER PRESSURE

| NO. OF PLATE | LENGTH OF GAPS IN MM. | | DIAMETER OF TERMINALS IN MM. | | METAL AND SHAPE | | FIELD CIRCUIT OF ALTERNATOR | | PRIMARY CIRCUIT OF TRANSFORMER | | | | CAPACITY IN MICROFARADS | DISCHARGE CIRCUIT OF CONDENSER | | EXPOSURE IN SECONDS | TRANSFORMER USED | MEDIUM | PRESSURE IN ATMOSPHERES‡ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gas under Pressure | Air | Gas under Pressure | Air | Gas under Pressure | Air | Resistance in Ohms* | Current in Amperes | Resistance in Ohms* | Power in Watts | E.M.F. in Volts† | Current in Amperes | | Self-Induction in No. of Turns of Coil | Fan Running | | | | |
| 842 | 0.6 | 5 | 2.3 | 4 | $Fe$, flat | $Fe$, r'nd | 0 | 5.5 | 4 | 200 | 23 | 24 | 0.007 | 0 | Yes | 50 | Lakon 15,000 | AIR | 3.3 |
| 839 | 1.1 | 5 | 2.3 | 4 | " | " | 0 | 5.2 | 4 | 270 | 27 | 20 | 0.007 | 0 | " | 70 | " | " | 7.3 |
| 833 | 0.2 | 5 | 2.3 | 4 | " | " | 0 | ... | 4 | ... | .. | .. | 0.007 | 0 | " | 40 | " | " | 14.0 |
| 837 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | 5.0 | 4 | ·170 | 17 | 23 | 0.007 | 143 | " | 60 | " | " | 14.0 |
| 859 | 0.2 | 5 | 2.3 | 4 | " | " | 0 | 3.5 | 4 | 150 | 17 | 17 | 0.007 | 0 | " | 240 | " | CO₂ | 3.7 |
| 858 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | 4.0 | 4 | 270 | 31 | 21 | 0.007 | 0 | " | 90 | " | " | 7.7 |
| 856 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | ... | 4 | ... | .. | .. | 0.007 | 0 | " | 50 | " | " | 14.0 |
| 855 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | ... | 4 | ... | .. | .. | 0.007 | 0 | " | 35 | " | " | 26.7 |
| 857 | 0.3 | 5 | 2.3 | 4 | " | " | 0 | ... | 4 | ... | .. | .. | 0.007 | 0 | " | 25 | " | " | 51.7 |
| 864§ | 0.3 | 5 | 2.3 | 4 | " | " | 0 | ... | 4 | ... | .. | .. | 0.007 | 0 | " | | " | CO₂ | |

\* Resistance over and above that of field coils of alternator and primary windings of transformer.

† Potential difference at terminals of transformer.

‡ Pressure as measured by gauge, in excess of normal atmospheric pressure.

§ Comparison spectrum inside, pressure spectrum outside.

Table XIV shows the effect of *increase of pressure*, using *air* as the gaseous medium. Plates 833 and 837 also show the result of placing self-induction in the discharge circuit of the condenser. As stated above, the influence of self-induction is not so marked as in the case of the spark in water.

Table XV deals with the effect of *increase of pressure*, with *carbon dioxide* as the gaseous medium. Plate 864 is to be compared with 858, the former being taken with the position of the spark spectrum at normal pressure and that of the comparison spectrum under approximately 7 atmospheres, reversed on the photographic plate. This was done to determine whether or not the shifts were genuine, and not due to unsymmetrical broadening. In measuring 864 the cross-hairs of the comparator were set upon the tips of the lines of the spectrum of the spark under pressure.

## TABLE XIV

### EFFECT PRODUCED BY CHANGE OF PRESSURE

#### AIR

| No. of Plate | | 842 | | | 839 | | | 833 | | | 837† | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure in Atmospheres* | | 3.3 | | | 7.3 | | | 14 | | | 14 | | |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters: positive unless otherwise stated. Absorption lines indicated by *a*; emission lines by *e*. | | | | | | | | | | | |
| 3587.10 | 5 | 2 | 0.05 | e | 6 | −0.01 | a | 6 | −0.01 | a | | | |
| 3606.85 | 6 | 2 | .06 | e | 2 | .14 | e | 7 | .05 | a | 2 | 0.26 | e |
| | | | | | | | | | .39 | e | | | |
| 3733.46 | 6 | 2 | .07 | e | 4 | .01 | a | 4 | .02 | a | 4 | .01 | a |
| 58.39 | 8 | 6 | .01 | a | 6 | .06 | a | 6 | .08 | a | | | |
| 65.70 | 5 | 2 | .09 | e | 2 | .15 | e | 7 | .05 | a | 2 | .16 | e |
| | | | | | | | | | .33 | e | | | |
| 67.32 | 7 | 2 | .09 | e | 6 | .06 | a | 6 | .07 | a | 6 | .05 | a |
| 3815.99 | 9 | 6 | .04 | a | 6 | .05 | a | 6 | .08 | a | 6 | .07 | a |
| 24.58 | 7 | 2 | .03 | e | 5 | .07 | a | 4 | .04 | a | 4 | .06 | a |
| 27.98 | 9 | 2 | .11 | e | 6 | .06 | a | 6 | .10 | a | 6 | .08 | a |
| 34.38 | 8 | 2 | .10 | e | 6 | .06 | a | 6 | .08 | a | 6 | .07 | a |
| 4045.98 | 10 | 5 | .03 | a | 5 | .05 | a | 5 | .07 | a | | | |
| 63.75 | 10 | 2 | .07 | e | 5 | .06 | a | 5 | .07 | a | | | |
| 4199.27 | 8 | 2 | .05 | e | 2 | .14 | e | 2 | .18 | e | | | |
| 4294.32 | 6 | 2 | .04 | e | 2 | .09 | e | 2 | .16 | e | | | |
| 4308.06 | 10 | 2 | .09 | e | 5 | .08 | a | 5 | .09 | a | | | |
| 25.94 | 10 | 2 | .07 | e | 5 | .04 | a | 5 | .10 | a | | | |
| 83.71 | 10 | 6 | .01 | a | 6 | .03 | a | 6 | .10 | a | | | |
| 4404.94 | 10 | 2 | .03 | e | 6 | .06 | a | 6 | .12 | a | | | |

\* In excess of normal atmospheric pressure.
† 143 turns of self-induction coil in discharge circuit of condenser.

## TABLE XV

### EFFECT PRODUCED BY CHANGE OF PRESSURE

#### CARBON DIOXIDE

| No. of Plate | | 859 | | | 858 | | | 856 | | | 855 | | | 857 | | | 864* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure in Atmospheres | | 3.7 | | | 7.7 | | | 14 | | | 26.7 | | | 51.7 | | | 7.3 | | |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters. Type of line in *italics*. Absorption lines indicated by *a*; emission lines, by *e*. | | | | | | | | | | | | | | | | | |
| 3587.10 | 5 | 2 | 0.02 | e | 2 | 0.04 | e | 7 | 0.06 | a | 4 | 0.08 | a | 4 | 0.10 | a | 2 | 0.06 | e |
| | | | | | | | | | .35 | e | | | | | | | | | |
| 3606.85 | 6 | 2 | .04 | e | 2 | .08 | e | 2 | .20 | e | 4 | .08 | a | 4 | .12 | a | 2 | .10 | e |
| 3733.46 | 6 | 2 | .03 | e | 2 | .04 | e | 4 | .02 | a | 4 | .06 | a | 4 | .06 | a | 2 | .06 | e |
| 58.39 | 8 | 2 | .07 | e | 6 | .02 | a | 6 | .04 | a | 4 | .07 | a | 4 | .14 | a | 6 | ... | a |
| 65.70 | 5 | 2 | .05 | e | 2 | .07 | e | 2 | .16 | e | 4 | .10 | a | 4 | .13 | a | 2 | .09 | e |
| 67.32 | 7 | 2 | .04 | e | 2 | .06 | e | 6 | .05 | a | 6 | .09 | a | 4 | .11 | a | 2 | .10 | e |
| 3815.99 | 9 | 2 | .06 | e | 6 | .05 | a | 6 | .06 | a | 4 | .10 | a | 4 | .14 | a | 6 | ... | a |
| 24.58 | 7 | 2 | .00 | e | 2 | .03 | e | 5 | .04 | a | 4 | .07 | a | 4 | .08 | a | 5 | ... | a |
| 27.98 | 9 | 2 | .06 | e | 2 | .10 | e | 6 | .08 | a | 6 | .11 | a | 4 | .16 | a | 2 | .15 | e |
| 34.38 | 8 | 2 | .05 | e | 2 | .08 | e | 6 | .06 | a | 6 | .09 | a | 4 | .16 | a | 5 | ... | a |
| 4045.98 | 10 | 2 | .03 | e | 5 | .04 | a | 5 | .04 | a | 5 | .10 | a | 4 | .14 | a | | | |
| 63.75 | 10 | 2 | .03 | e | 2 | .04 | e | 5 | .07 | a | 5 | .11 | a | 4 | .18 | a | | | |
| 4199.27 | 8 | 2 | .03 | e | 2 | .06 | e | 2 | .11 | e | 2 Very diffuse | | | Lacking | | | | | |
| 4294.32 | 6 | 2 | .02 | e | 2 | .02 | e | 2 | .08 | e | 2 | .22 | e | 2 Faint & diff. | | | | | |
| 4308.06 | 10 | 2 | .05 | e | 2 | .10 | e | 5 | .09 | a | 5 | .10 | a | 5 | .17 | a | | | |
| 25.94 | 10 | 2 | .06 | e | 2 | .06 | e | 5 | .06 | a | 5 | .12 | a | 5 | .15 | a | | | |
| 83.71 | 10 | 2 | .03 | e | 6 | .05 | a | 6 | .06 | a | 6 | .08 | a | 6 | .15 | a | | | |
| 4404.94 | 10 | 2 | .04 | e | 2 | .08 | e | 6 | .04 | a | 6 | .10 | a | 6 | .11 | a | | | |

\* Comparison spectrum on inside region of plate.

A study of the pressure shifts[21] of the lines in the tables indicates:

1. That the shifts of certain bright lines, which remain fairly sharp and show no sign of reversal at high pressures, vary directly as the pressure.

2. That the shifts of certain bright lines at high pressures appear to be less than the law of direct proportionality would require.

3. That the shifts of certain dark lines increase directly with the pressure, though the shift per atmosphere is usually less than in the case of bright lines.

4. That when, with increasing pressure, a bright line is first accompanied and subsequently replaced by a dark line, the presence of the dark line appears to increase the shift of the bright line abnormally in the first instance, whereas the shift of the dark line, after the disappearance of the bright line, is usually comparatively small, and increases with the pressure.

The absorption and shifts, as apparent on 864 (7.3 atmospheres) are both slightly greater than those on 858 (7.7 atmospheres). This is contrary to the general law: greater pressure, greater absorption and shift. It indicates that the results may not be very reliable, and throws doubt on the conclusion, suggested by a comparison of Tables XIV and XV, that for a given pressure the air plates show respectively greater absorption and shift than the corresponding carbon dioxide plates.

Table XVI gives a comparison of the effects of increasing pressure in the case of the spark in air, and of decreasing self-induction in the case of the spark in water. Plate 659 (water) shows a trifle less absorption than 842 (air). It will be noticed that the values of the shift are distinctly less. The same is true of the other pairs, 658, 839; and 665, 833: in all three sets the water plate shows a little less absorption but considerably less shift. Determining the means of the measured shifts of the emission and absorption lines, we obtain the data given in Table XVII. In these three sets the pairs of plates in each show very nearly the same spectrum. If we assume that the pressure developed in the spark under water determines the shift, we may calculate the pressure. From the first set, Plates 842 and 659, using the emission lines only, the pressure in the water-spark is found to be 1.4 atmospheres; from the second set, Plates 839 and 658, 3.5 atmospheres; and from the third set, Plates 833 and 665, 9.1 atmospheres. Of course, the above assumption may not be justifiable.

The variation in the shift and absorption in the high-pressure air plates, taken under what appeared to be identical conditions, may be due to differences in the length of the internal gap, which could not be adjusted accurately and therefore widened rapidly during the exposure.

Two sets of plates, using for one member of each set metal terminals made from a nickel five-cent piece (25 per cent. nickel and 75 per cent. copper), and for the other approximately chemically pure nickel, seem to show that less absorption is given by the alloy than by the pure metal. The gas used was carbon dioxide, and the pressure approximately 14.3 atmospheres for the first set and 20 for the second.

At pressures above 50 atmospheres the air-lines are not present in the spectrum photographed.

Further results of this part of the investigation are as follows:

As previously mentioned, the influence of self-induction lies in the same direction as with the spark in water, but the effect is less marked. On the other hand, the effect of an increase in the length of the *auxiliary gap* appears to be great, tending toward extreme absorption. The iron line λ 3765.70 is clearly of type 7 (absorption line superposed on emission but with the violet component of the latter lacking) on a plate taken at high dispersion under a pressure of 13.3 atmospheres with an auxiliary gap of 20 mm. This line is not usually reversed.

In our experiments with gases under pressure it was possible to carry the absorption farther toward the red end of the spectrum than with the discharge in liquids. The iron line λ 4415.29 at 27.3 and 53.3 atmospheres' pressure in carbon dioxide is clearly of type 6 (unsymmetrically reversed;

_____

[21] The measurements of these shifts are frequently liable to errors of several hundredths of a tenth-meter, due in part to the character of the lines.

## TABLE XVI

### COMPARISON OF SHIFT SHOWN BY "AIR" AND "WATER" PLATES WHICH SHOW SIMILAR DEGREES OF ABSORPTION

| No. of Plate | | 842 Air | 659 Water | 839 Air | 658 Water | 833 Air | 665 Water |
|---|---|---|---|---|---|---|---|
| Pressure in Atmospheres* Self-Induction in No. of Turns | | 3.3 | 143 | 7.3 | 27 | 14.0 | 0 |
| Wave-Lengths | Intensities | Shift toward red in tenth-meters; positive unless otherwise stated. Absorption lines indicated by $a$; emission lines by $e$. | | | | | |
| 3587.10 | 5 | 2  0.05  e | 2  0.02  e | 6  −0.01  a | 7  −0.09  a   —  e | 6  −0.01  a | 4  −0.01  a |
| 3606.85 | 6 | 2  .06  e | 2  .01  e | 2  .14  e | 2  .08  e | 7  .05  a  .39  e | 7  − .01  a  .28  e |
| 3733.46 | 6 | 2  .07  e | 2  —  e | 4  .01  a | 4  .03  a | 4  .02  a | 4  − .01  a |
| 58.39 | 8 | 6  .01  a | 3  .07  e | 6  .06  a | 6  .02  a | 6  .08  e | 5  .02  a |
| 65.70 | 5 | 2  .09  e | 2  .02  e | 2  .15  e | 2  .09  e | 7  .05  a  .33  e | 3  .21  e |
| 67.32 | 7 | 2  .09  e | 2  .03  e | 6  .08  a | 7  .01  a  .32  e | 6  .07  a | 4  .02  a |
| 3815.99 | 9 | 6  .04  a | 3  .05  e | 6  .05  a | 6  .00  a | 6  .08  a | 6  .03  a |
| 24.58 | 7 | 2  .03  e | Lacking | 5  .08  a | 4  .04  a | 4  .04  a | 4  .03  a |
| 27.98 | 9 | 2  .11  e | 3  .02  e | 6  .06  a | 7  − .01  a  .35  e | 6  .10  a | 4  .02  a |
| 34.38 | 8 | 2  10  e | 2  .03  e | 6  .06  a | 6  − .01  a | 6  .08  a | 4  .02  a |
| 4045.98 | 10 | 5  .03  a | 2  .01  e | 5  .05  a | 6  .02  a | 5  .07  a | 4  .06  a |
| 63.75 | 10 | 2  .07  e | 2  .03  e | 5  .06  a | 6  .06  a | 5  .07  a | 4  .02  a |
| 4199.27 | 8 | 2  .05  e | 2  .02  e | 2  .14  e | 2  .06  e | 2  .18  e | 2  .11  e |
| 4294.32 | 6 | 2  .04  e | 2  .02  e | 2  .09  e | 2  .02  e | 2  .16  e | 2  —  e |
| 4308.06 | 10 | 2  .09  e | 2  .02  e | 5  .08  a | 6  − .05  a | 5  .13  a | 6  .02  a |
| 25.94 | 10 | 2  .07  e | 3  .02  e | 5  .04  a | 6  − .01  a | 5  .11  a | 2  .01  e |
| 83.71 | 10 | 6  .01  a | 3  .05  e | 6  .03  a | 6  − .01  a | 6  .10  a | 6  .02  a |
| 4404.94 | 10 | 2  .03  e | 3  .03  e | 6  .06  a | 6  − .11  a | 6  .12  a | 6  .02  a |

*Above normal atmospheric pressure.

## TABLE XVII

### CALCULATION OF PRESSURE PRODUCED IN SPARK UNDER WATER

| No. of Plate | 842 Air 3.3 | 659 Water | 839 Air 7.3 | 658 Water | 833 Air 14.0 | 665 Water |
|---|---|---|---|---|---|---|
| Mean shift as determined from data given in Table XVI................. | 0.068 | 0.028 | 0.130 | 0.063 | 0.170 | 0.110 |
| Resultant calculated pressure in the spark under water...................... | 1.4 atmospheres | | 3.5 atmospheres | | 9.1 atmospheres | |

see Plate XXI, which shows the maximum absorption given in these regions with the spark in carbon dioxide). In the spark under water, only the faintest shadow of a reversal could be obtained.

Our spectra of the spark in water and in air under pressure differ in the following details:

*a*) Some emission lines show reversal more easily in air than in water, while with other lines the reverse is true.

*b*) In water the lines of type 3 (unsymmetrically broadened emission lines) are more numerous than in air. However, as mentioned above, in the less refrangible regions near $\lambda\lambda$ 4880 and 4900 several strong lines occur which are unsymmetrically broadened. These are similarly affected in water under high absorption conditions.

*c*) In gases under pressure, the enhancement of certain lines previous to reversal is very marked.

*d*) The non-uniformity in the intensity of the continuous spectrum in the air plates under low absorption conditions is in marked contrast to the uniformity of intensity which obtains in the water spectrum.

## III.  BEARING OF THE SPARK PHENOMENA ON THE PRESSURE THEORY OF TEMPORARY STARS

We have now to consider the bearing of our results on Wilsing's theory of temporary stars.  In this theory Wilsing ascribes the chief characteristics of the spectra of *Novae* to pressure, and finds a close analogy between their spectra and that of the spark in water.  The conditions of the laboratory experiments were such that his spark in water showed pairs of bright and dark lines, somewhat resembling in appearance the compound lines in the spectra of temporary stars.  Wilsing suggests that luminescence phenomena may play some part in these stellar spectra; but he regards pressure as the prime factor, and as our results bear only on this point, we shall confine our conclusions to pressure effects.

It may be advantageous at this juncture to recall the chief phenomena of temporary stars, as exemplified in the case of *Nova Persei*.  On February 21, 1901, a photograph of the constellation *Perseus* showed nothing unusual, and demonstrated that no unknown star as bright as the twelfth magnitude could be present.  The next night the *Nova* was discovered visually by Anderson, who estimated its magnitude to be 2.7.  The brightness rose to a maximum of 0 mag. on February 23, and then decreased steadily to a minimum of about 1.8 mag. on February 28, after which it rose, in a few hours, to about 1.6 mag.  Subsequently the light showed irregular fluctuations, amounting to as much as two magnitudes in a single day.

In April the maxima and minima became more regular, with a period of from four to six days, and this continued until June, when the range of variation became less marked.  By the middle of July the magnitude was about 6.5, at which it remained fairly constant for some time, ultimately fading gradually away.

When first discovered the *Nova* was white in color, but within a few days it became red, and so remained, with some modifications of tint at maxima and minima, until July.  At this time, and subsequently, both in color (greenish) and spectrum, the *Nova* resembled a planetary nebula.

The changes in the spectrum were very remarkable, though in all respects typical of temporary stars.  At first the spectrum was apparently continuous, but by February 24 broad and diffuse bright bands had appeared, accompanied on their violet sides by broad dark bands.  The strength of the continuous spectrum, and the small degree of absorption in the dark bands, made the contrast very slight.  It rapidly increased, however, as the photographs reproduced in Plate XXIII indicate.  The bright hydrogen bands, which extended well out into the ultra-violet, were remarkably broad, averaging over 30 tenth-meters in width.  The Lick Observatory measures of February 25 show the maxima of these bright bands to be displaced toward the violet about 8 tenth-meters from the normal positions of the hydrogen lines.  By the middle of March they were displaced about 4 tenth-meters toward the red.  The broad dark hydrogen bands, on the other hand, were displaced from 19 to 25 tenth-meters toward the violet.  The dark H and K bands were similarly displaced about 16 tenth-meters, while the displacement of the dark D band was about 27 tenth-meters in the same direction.  These shifts are corrected for radial velocity, which was easily measured with the aid of the narrow dark reversals of the bright H and K bands.  These lines gave a practically constant mean value of about +6 km., and the narrow dark D reversals gave a velocity of the same order.

A discussion of the displacements of the *Nova* lines, based by Campbell and Wright[22] on their measures of the Mount Hamilton photographs, and by Becker[23] on measures of photographs made by himself at Glasgow, brings out the fact that the displacements of the lines are proportional to the wave-lengths, and independent of the particular elements to which they belong.  The obvious bearing of this important conclusion on Wilsing's pressure theory will be mentioned later.

As the brightness of the *Nova* decreased the continuous spectrum faded, and the bright bands gained in contrast.  The fluctuations in brightness, however, were reflected in the spectrum.  A rise

[22] Lick Observatory *Bulletin*, No. 8.          [23] *Trans. Roy. Soc. Edinburgh*, Vol. XLI, Part II, No. 10.

to maximum was accompanied by a strengthening of the continuous spectrum relatively to the bright lines, but the latter regained their contrast on the approach to a minimum. These fluctuations continued for a time, but the gradual decline in the star's light resulted in a corresponding decrease in the intensity of the continuous spectrum and of the dark lines, while the bright lines became more prominent. During this time there were many changes in the relative intensities of the bright lines. K decreased greatly, and soon disappeared entirely. H doubtless shared a similar fate, but the broad $H\epsilon$ line prevented it from being observed. $H\beta$ became narrower and sharper, and the relative intensities of its several components underwent marked variations. The dark bands on the more refrangible edge of the bright hydrogen lines, which were at first broad and poorly defined, changed about the middle of March to sharp double lines. Before they finally disappeared the duplicity vanished. The narrow dark D lines, and the bright band upon which they were projected, were of special interest. The bright band gradually moved toward the violet so that the two dark lines, which were at first nearly central on the band, were in April at its less refrangible edge. The dark line on the more refrangible edge of this band, nearly in the position of $D_3$, gave place to a much broader, but fainter, band extending toward the violet.

Spectroscopic observations of *Nova Persei* were interrupted during May and June, on account of its proximity to the Sun. When first observed by Pickering in July, the spectrum was found to be that of a nebula, the nebular lines being represented by broad bright bands. Certain anomalies in the *Nova's* spectrum, such as the abnormal brightness and altered position of a line near the place of $H\zeta$, were explained by Wright's photographs of the spectra of nebulæ. A new nebular line was found which satisfactorily accounted for the *Nova* line. The narrow dark absorption lines at D and at H and K indicated no change in the radial velocity of the star. The broad bright bands, which contained many maxima and minima, were displaced from 8 to 13 tenth-meters toward the violet. Campbell and Wright[24] pointed out that these displacements were in all cases proportional to the wave-lengths of the bands. The principal bands showed a striking agreement with the known lines of the nebulae, and with bands observed in the spectrum of *Nova Aurigae*.

As already remarked, it is not our intention, in the present paper, to attempt a discussion of temporary stars or to deal with their general theory. The above brief outline of the principal spectroscopic phenomena of *Nova Persei* will suffice for our purpose, which is to point out the bearing of our experiments on Wilsing's pressure theory. We are unable to accept his theory, for the following reasons:

1. In the spectrum of the spark in liquids or compressed gases, the occurrence in the violet of pairs of bright and dark lines represents a condition of moderate pressure. When the pressure is increased (see Plate XXI), the bright lines widen and finally disappear, giving place to dark lines. At the high pressures supposed to exist in temporary stars, dark lines should appear on a continuous spectrum, rather than pairs of bright and dark lines, if a close analogy be assumed to exist between the stellar and the laboratory phenomena.

2. Our experiments, in harmony with theoretical considerations, show that selective absorption is a function of wave-length, and that line reversals begin in the ultra-violet, and advance toward the red with increasing pressure. If high pressure were a dominant factor in temporary stars, we should therefore expect to find a marked difference in the character of the reversals in different parts of the spectrum. Observations of *Nova Persei* and other temporary stars showed, however, a remarkable similarity of the hydrogen lines, from $H\alpha$ in the red to the last recorded members of the series in the ultra-violet. In this connection it may be recalled that some of the Wolf-Rayet stars show the more refrangible hydrogen lines dark, while the less refrangible members of the series are only partially reversed or bright.

3. Pressure displacements in the laboratory are invariably toward the red end of the spectrum. The slight apparent shifts toward the violet of absorption lines in the spectrum of the spark in water

[24] *Loc. cit.*

are probably due to the presence of bright lines on their less refrangible side. Wilsing and Vogel have similarly explained the great displacements toward the violet of the dark bands in temporary stars, attributing them to the effect of overlapping bright bands.[25] Unfortunately, however, this explanation can account neither for the relative displacement of the dark bands after they were clearly separated from the bright bands,[26] nor for the displacement of the bright bands when photographed at the Lick Observatory on February 25, and again after the spectrum had become nebular.[27]

4. In Humphrey's investigations on the arc spectra of sodium and calcium, at a pressure of $10\frac{1}{2}$ atmospheres, the shifts for D (mean of $D_1$ and $D_2$), and for H and K, were as follows:[28]

|   | $\Delta\lambda$, observed | $\Delta\lambda$, reduced to $\lambda$ 4000 |
|---|---|---|
| D | 119 | 81 |
| H | 25 | 25 |
| K | 22 | 22 |

As the shifts of these lines were found to increase in direct proportion to the pressure, the respective displacements of the D and the K lines in *Nova Persei*, when reduced to $\lambda$ 4000, should be approximately in the ratio 81:22 if caused by pressure. It has been shown, however, that the displacements of these lines in the *Nova* were approximately equal, when reduced to the same wavelength. It is therefore impossible to see how the position or the character of the *Nova* lines could have been due to pressure.

It is not, of course, our intention to deny that differences of pressure existed in various parts of the mass of gases and vapors that constituted *Nova Persei*. We nevertheless conclude that the dominant features of the spectra of temporary stars are probably determined by some other cause, which we hope to investigate on a future occasion.

## IV. SUMMARY

In the course of this investigation on the spectrum of the high potential discharge in liquids and compressed gases, undertaken for the purpose of testing Wilsing's pressure theory of temporary stars, the following results have been obtained:

1. Wilsing's observation that the spectrum of the iron spark in water contains compound lines, each consisting of a bright line on the less refrangible side of a dark line, is confirmed by our experiments.

2. By varying the self-induction in the discharge circuit of the condenser, the character of the spectrum can be greatly changed. With large self-induction, the spectrum of the spark between iron poles in water consists of bright lines, and resembles the spectrum of the iron spark in air. As the self-induction is decreased, dark lines begin to appear, nearly at the normal positions of the iron lines, while the bright lines are increasingly shifted toward the red and become more diffuse. With no self-induction, the bright lines almost entirely disappear, giving place to a spectrum of dark lines. These remarks apply especially to the region of the iron spectrum comprised between $\lambda$ 3600 and $\lambda$ 4500. It should be added, however, that with our apparatus some of the bright lines persist even when there is no self-induction in the discharge circuit.

3. An increase in the length of the auxiliary air spark; in the diameter of the water-spark terminals; in the diameter of the auxiliary air-spark terminals; in the capacity of the condenser; and perhaps in the temperature of the water: apparently tend to increase the absorption. The absorption is decreased by increasing the length of the spark in water and the self-induction in the discharge circuit; by the insertion in the discharge circuit of non-inductive resistance; and probably by other changes in the electrical conditions under which the discharge takes place.

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[25] Vogel, "Ueber das Spectrum der *Nova Persei*," *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften*, Berlin, March 21, 1901.

[26] Sidgreaves, *Observatory*, May, 1901, p. 192.

[27] Lick Observatory *Bulletin*, No. 8.

[28] *Astrophysical Journal*, Vol. VI (1891), pp. 192 and 210.

4. In the spectrum of the spark in salt solutions the absorption seems to increase with the strength of the solution. This appears to be due, in large part, to a chemical effect, the presence of the salt producing a more rapid pulverization of the electrodes.

5. Manganese, antimony, bismuth, tin, gold, calcium, silver, nickel, cobalt, titanium, aluminium, lead, cadmium, and magnesium show absorption phenomena similar to those obtained with iron.

6. In an investigation of the positions of lines under different physical conditions, made with high dispersion, it was found that many of the causes stated above to be capable of changing the degree of absorption, at the same time produced displacements of the lines in the spectrum.

7. The passage of a high potential discharge is accompanied by the sudden production of a very high temperature and the liberation of a large quantity of metallic vapor. Both causes unite to bring about a sudden increase of pressure. The amount of metallic vapor produced in unit time, and consequently the effective pressure and degree of absorption, increases with the strength of the current and the difference of potential between the terminals. The decreased number of oscillations in the condenser discharge, caused by the insertion of self-induction, must tend to reduce this quantity, and consequently to diminish the absorption and the displacement of the lines. The effect of changing other conditions that determine the intensity and suddenness of the discharge may be accounted for on similar grounds.

8. In the case of lines in the same part of the spectrum, those of greatest intensity are usually the first to show evidences of reversal. In the case of lines of equal intensity (with some exceptions), those of shortest wave-length reverse first. The reversals advance toward the red end of the spectrum as the conditions become more favorable for increased absorption.

9. These reversal phenomena, in harmony with theoretical considerations, show that selective absorption, like general absorption, is a function of the wave-length.

10. In the spectrum of the spark between iron electrodes in compressed gases, it was found that pairs of bright and dark lines occur, similar to those obtained with the spark in water.

11. Reversal phenomena, similar to those obtained with the spark in water by varying the self-induction, were observed in gases as the pressure was increased.

12. At air pressures ranging from 1 to 20 atmospheres, the displacements of certain spark lines which are not reversed at these pressures, increase in direct proportion to the gauge pressure of the gas.

13. Certain dark lines, when reversed at low pressures, give pressure shifts which increase in direct proportion to the pressure, but usually at a less rapid rate than in the case of the bright lines.

14. When a bright line is beginning to show signs of reversal, or when bright and dark lines occur in pairs, the observed pressure shifts are irregular, probably because the overlapping lines prevent settings from being made on their true centers.

15. In comparing our pressure displacements with those of Humphreys (Plate XXII), it will be noted that in the case of several lines our displacements are larger for the same gauge pressure.

16. Our conclusions as to the bearing of the above results on Wilsing's pressure theory of temporary stars are given on p. 64.

We wish to express our thanks to Mr. Ellerman and to Mr. Hartley, for making the enlargments of our photographs which are reproduced in the Plates.

PLATE XVI



CIRCULAR TABLE, SHOWING APPARATUS FOR SPARK IN LIQUIDS AND
COMPRESSED GASES

PLATE XVII



THE SPARK SPECTRUM OF IRON IN AIR (1), IN WATER (2, 3, 4),
AND IN SODIUM CHLORIDE SOLUTIONS (5, 6)
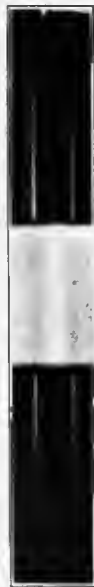
PLATE XVIII



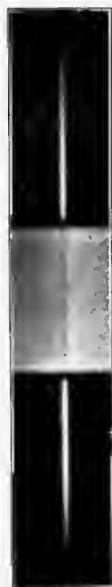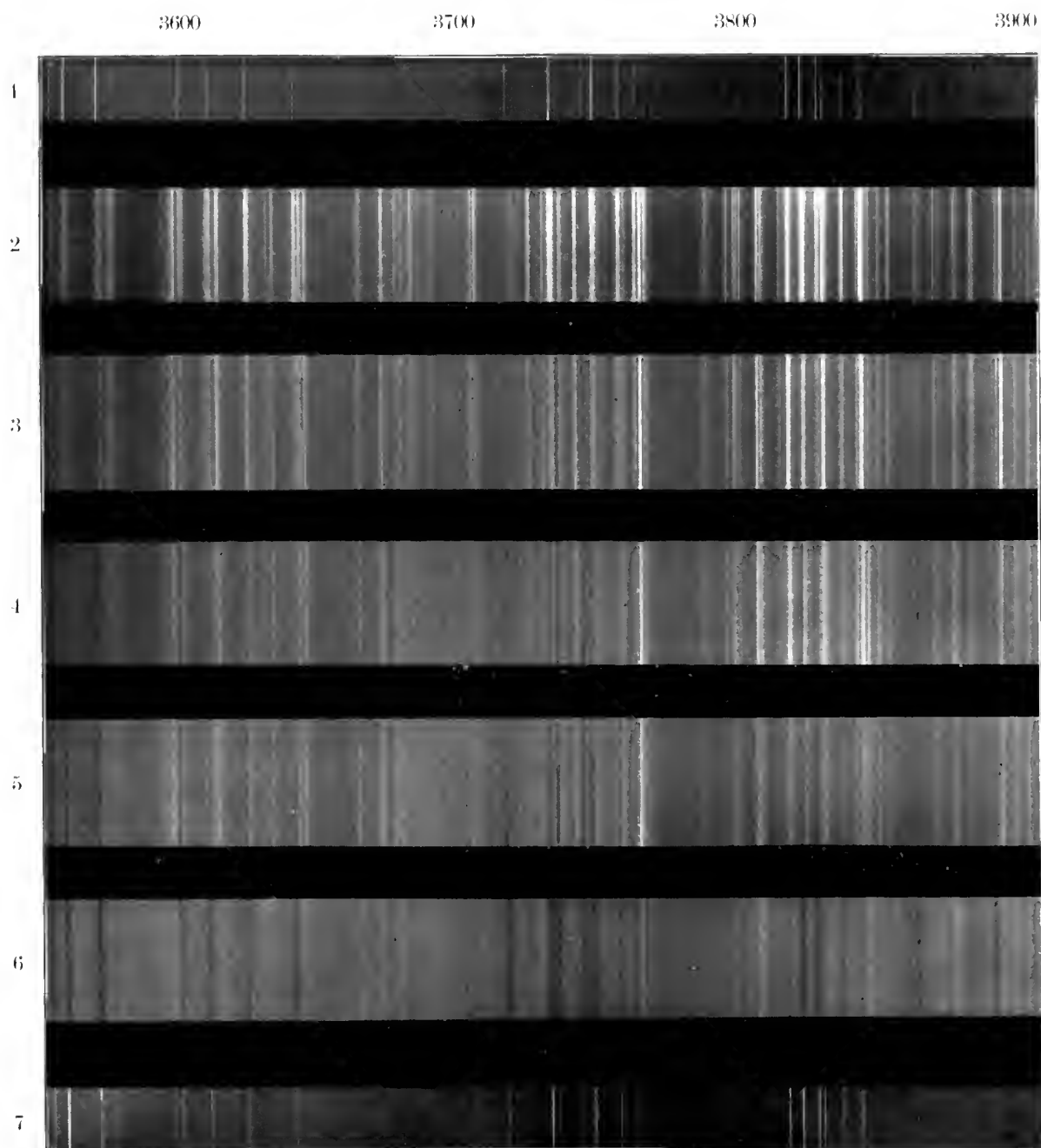TYPES OF LINES IN THE SPECTRUM OF THE IRON SPARK
IN WATER

PLATE XIX



EFFECT OF SELF-INDUCTION ON THE SPARK SPECTRUM OF IRON IN WATER

1 and 7. Spark in air at atmospheric pressure.
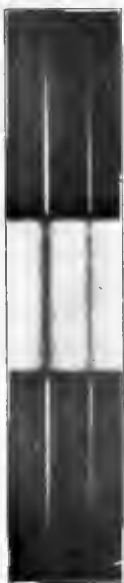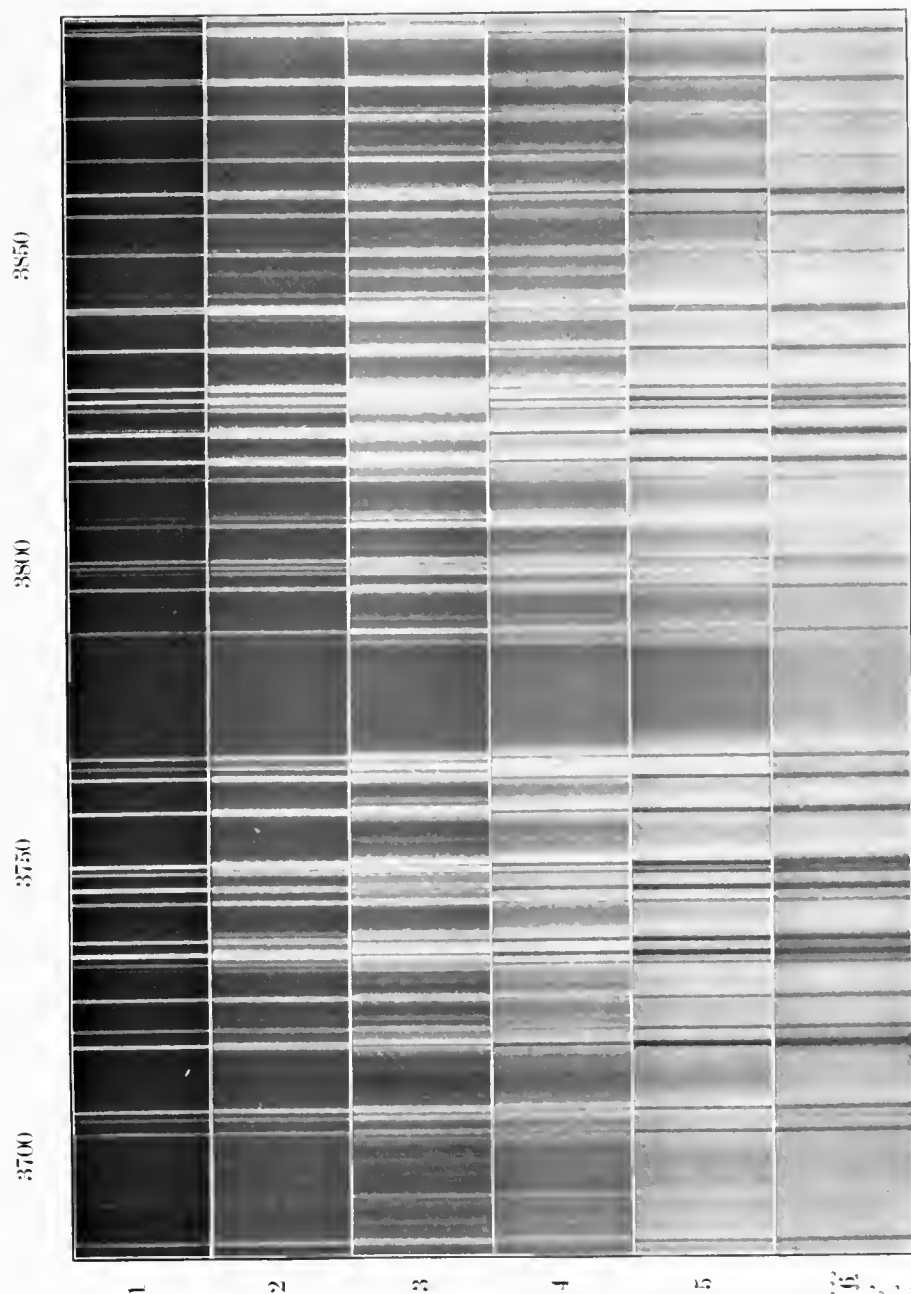2 to 6. Spark in water, showing changes caused by increasing self-induction.

PLATE XX



TYPES OF LINES IN THE SPECTRUM OF THE IRON SPARK
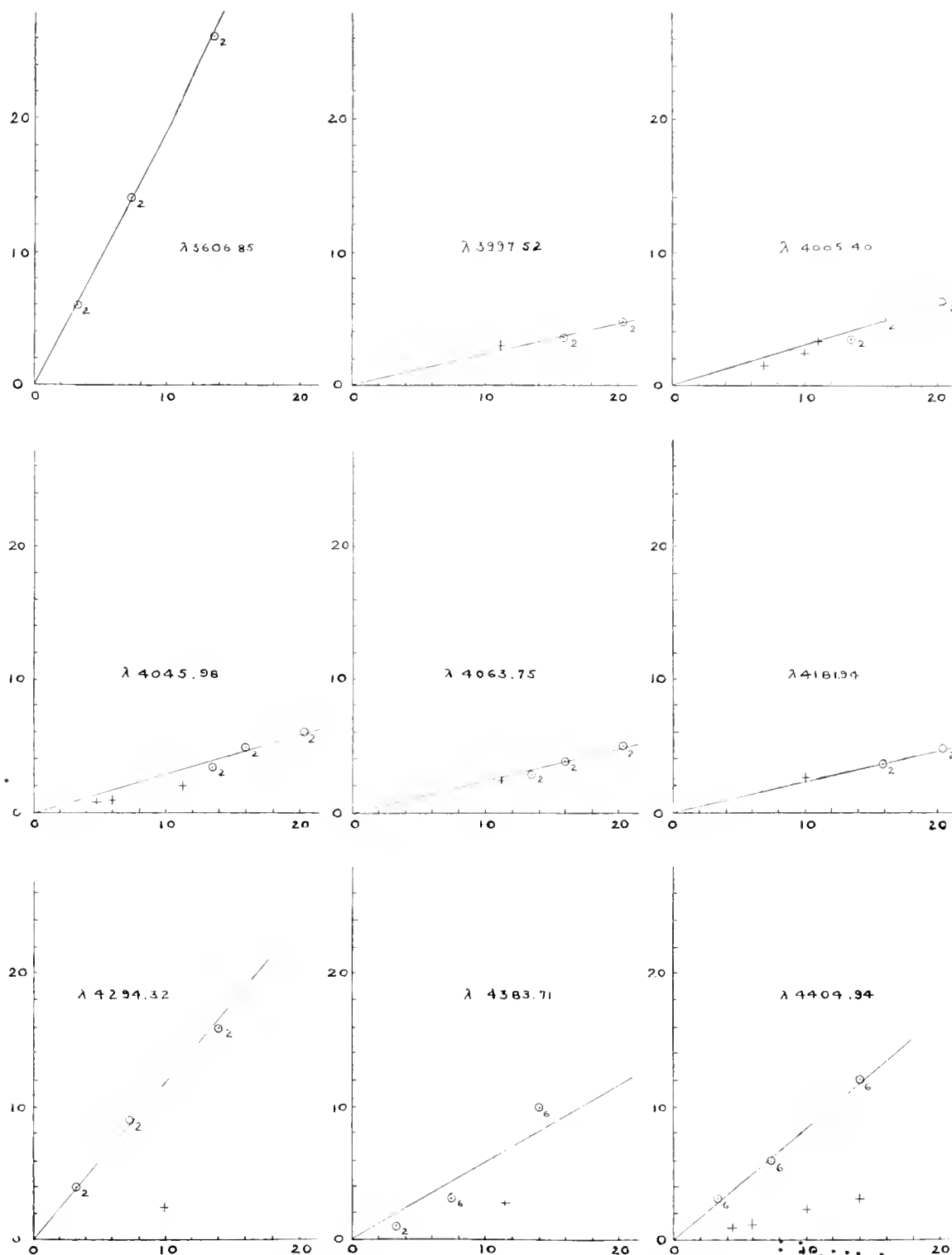IN COMPRESSED GASES

PLATE XXI



THE SPARK SPECTRUM OF IRON IN COMPRESSED GASES

1. In air at atmospheric pressure.
2. In air at 3.3 atmospheres.
3. In air at 7.3 atmospheres.
4. In air at 14 atmospheres.
5. In CO₂ at 27.3 atmospheres.
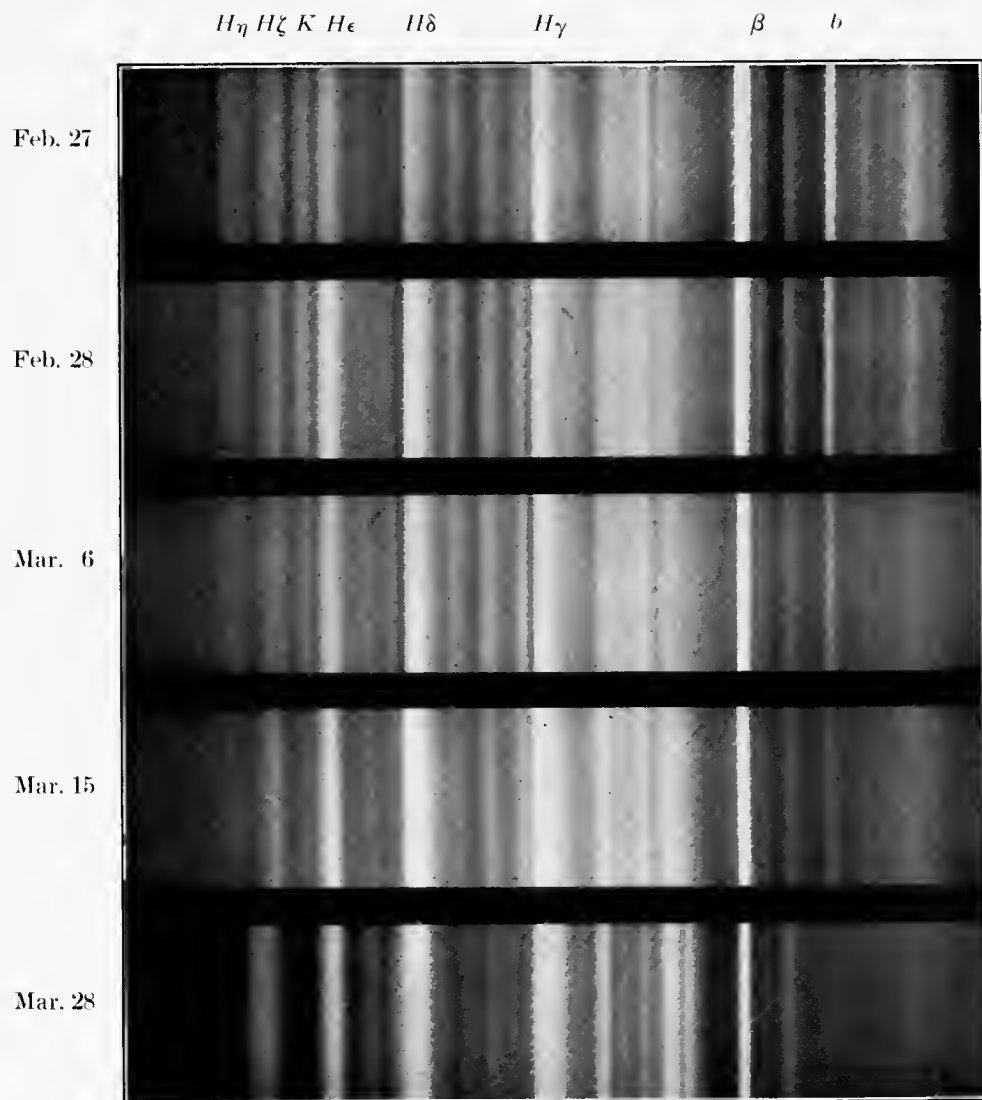6. In CO₂ at 53.3 atmospheres.

PLATE XXII



DISPLACEMENTS OF IRON LINES IN COMPRESSED AIR

Ordinates are Displacements, in hundredths of a tenth-meter. Abscissae are Pressures in Atmospheres.
Humphrey's values are indicated thus +.

PLATE XXIII

Hη Hζ K Hε    Hδ       Hγ              β     b

Feb. 27

Feb. 28

Mar. 6

Mar. 15

Mar. 28

SPECTRUM OF *NOVA PERSEI*

PHOTOGRAPHED WITH THE 40-INCH YERKES TELESCOPE BY FERDINAND ELLERMAN